Canada Alberta

FOREST RESOURCE DEVELOPMENT AGREEMENT
ENTENTE SUR LA MISE EN VALEUR DES RESSOURCES FORESTIERES

Canada Alberta

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The Canada-Alberta Forest Resource Development Agreement is a subsidiary agreement of the Canada-Alberta Economic and Regional Development Agreement, which provides coordination and cooperation between the governments of Alberta and Canada in areas of Alberta's economic development.

The Canada-Alberta Forest Resource Development Agreement is funded equally by the governments of Canada and Alberta, from April 1, 1984, to March 31, 1989.

Its primary objectives are to ensure the long-term availability of timber supplies; to optimize timber uses; and to contribute to the growth and diversification of Alberta's economy.

The Agreement comprises three programs: Reforestation; Applied research, technology transfer and opportunity identification; and Public information, evaluation and administration. These programs are managed by a joint Directorate and are implemented by the Canadian Forestry Service and the Alberta Forest Service.

L'Entente Canada-Alberta sur la mise en valeur des ressources forestières est auxiliaire à l'Entente Canada-Alberta sur le développement économique et régional, qui vise à assurer la coordination et la coopération des deux gouvernements relativement au développement économique de l'Alberta.

L'Entente Canada-Alberta sur la mise en valeur des ressources forestières est financée à parts égales par les gouvernements du Canada et de l'Alberta, et a cours du 1er avril 1984 au 31 mars 1989.

Ses objectifs principaux sont assurer la disponibilité à long terme de réserves de bois; optimiser leur utilisation; et contribuer à la croissance et la diversification de l'économie de la province.

L'Entente comprend trois programmes: Reboisement; Recherche appliquée, transferts de connaissances techniques et relevé des occasions; et Information, évaluation et administration. Ces programmes sont gérés par un Bureau de direction conjoint, et mis en oeuvre par le Service canadien des forêts et le Service forestier de l'Alberta.

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DIMENSIONAL STABILIZATION
STATE OF THE ART REVIEW
FP 2.4.1

ALBERTA RESEARCH COUNCIL
INDUSTRIAL TECHNOLOGIES DEPARTMENT
FOREST PRODUCTS PROGRAM[1]

1987

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[1]Edmonton, Alberta

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Summary

The dimensional stability of reconstituted wood products is an important consideration in the continued and widened acceptance of such structural panel products as waferboard and oriented strandboard. A review of the literature has shown that normal process variables such as wood furnish, resin type and level and press conditions can dramatically affect the linear expansion and total and irreversible thickness swelling that occur when panels are exposed to changes in moisture. Other treatments, such as steam and heat treatment, impregnation and acetylation, are being applied to both the raw wood furnish and the finished panels in an attempt to increase dimensional stability without an excessive loss in strength and bonding properties.

Consensus is slowly being reached on the effect of some of the basic variables on the dimensional stability of reconstituted wood products. However, complex interactions can occur between process variables to further change basic behavior. In addition, the test methods used to measure stability have been found to influence results. Thus, meaningful comparisons between data sets are often very difficult and apparently contradictory results are often both valid.

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1.0 Introduction

1.1 Dimensional Stability of Wood and Wood Products

Wood is a hygroscopic material which swells as it absorbs moisture and shrinks as it loses moisture below the fiber saturation point. In solid wood, the non-uniformity of these dimensional changes results in warping and grain-raising among others. In plywood the dimensional changes on water absorption occur mainly in the thickness dimension but boards generally return close to their original dimensions upon drying.

Reconstituted wood products, such as particleboard, flakeboard, waferboard and oriented strandboard (OSB) all generally exhibit poorer dimensional stability than plywood or solid wood. The thickness swelling of these products is greater than would be expected from the normal shrinking and swelling of the wood particles. In addition, the swelling of these products usually has an irreversible component. This is clearly illustrated in Figure 1 (Heebink and Hefty, 1969).

The non-recoverable, residual or irreversible thickness swelling that remains when the boards are redried is also called 'springback'. The underlying cause for this behavior is believed to be in part due to the release of residual compressive stresses imparted to the board during pressing of the mat in the hot press (Gatchell, Heebink and Hefty, 1966).

Dimensional stability of reconstituted wood panels can be affected by

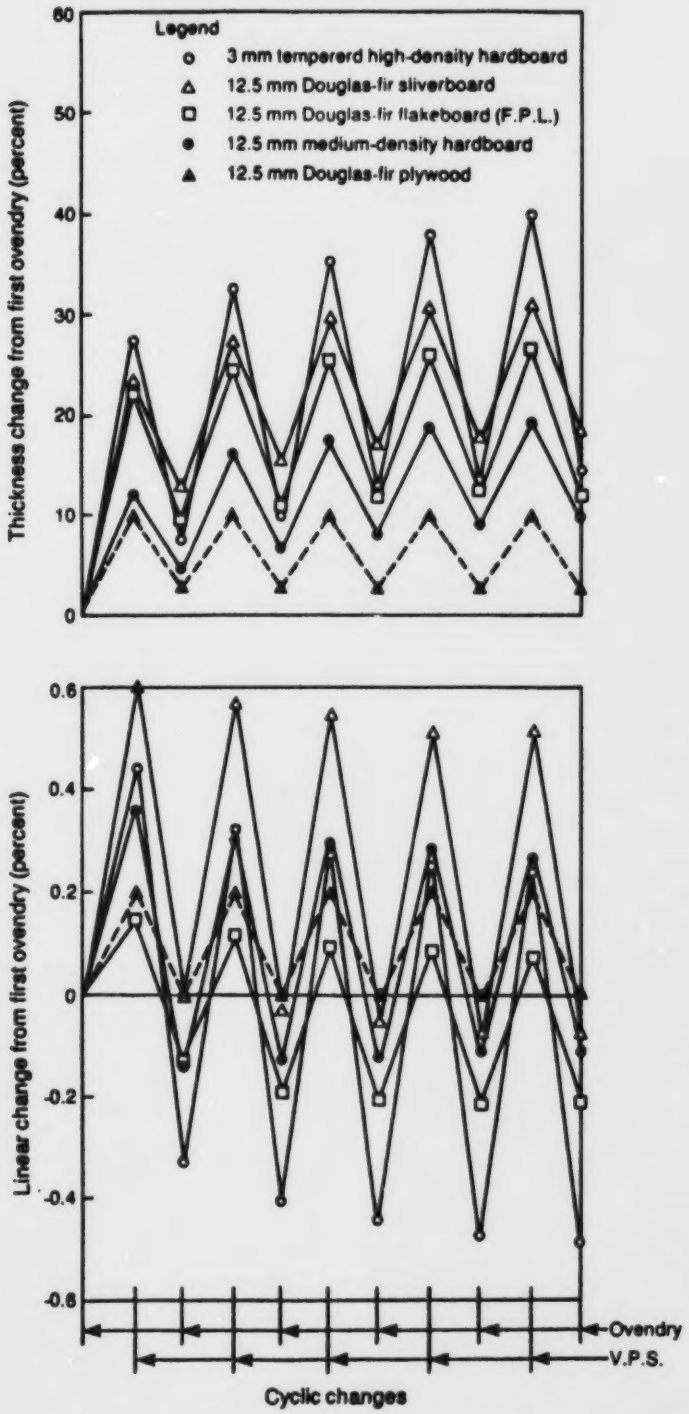

Figure 1: Typical thickness and linear changes for plywood and four panel products. (Drawing after Heebink and Hefty, 1969)

most process variables such as wood furnish, flake size and geometry, resin level and type and pressing conditions. Improved dimensional stability should be possible through a better understanding of these variables as well as by special treatments such as acetylation, heat treatments and coatings. Improving the dimensional stability of waferboard and oriented strand board must not be a goal in itself to the extent that the other physical properties of the board, such as modulus of elasticity, modulus of rupture and internal bond are adversely affected or the product becomes prohibitively expensive.

1.2 Waferboard and Oriented Strandboard

Reconstituted wood products are made from a wide variety of wood furnish. Names of the different types of wood panel products usually reflect the type of furnish used, but clear divisions do not always exist between board types.

Definitions for the different types of wood furnish commonly used in Canada are given in the Canadian Standards CAN3-0188.1-M78 ' Interior Mat-Formed Wood Particleboard ' and CAN3-0437.0-M85 ' Waferboard and Strandboard '. These definitions have been summarized in Table 1.

Waferboard and Oriented Strandboard are structural panel products made from wafers or strands of wood, blended with water and a boil proof binder. The wood particles are laid down in a thick mat in either a random or oriented fashion and bonded under heat and pressure to give a building panel. These panels have been accepted for a wide variety of

Table 1. : Definitions of Different types of Wood Furnish

Wood Furnish means the prepared particles including fibres from which the board is formed;

Fibre means a material in which the wood is reduced to a predominately fibrous form by grinding in an attrition mill. It differs from wood particles in that the morphological structure of the original wood is destroyed;

Particles means small discrete wood elements that generally retain the morphological structure of the wood from which they are derived. (particles in particleboard are generally derived from primary mill residue and are generally indefinite in size and shape except where solid wood is processed in flaking equipment.);

Chip means a small piece of wood chopped off a block by axe-like cuts as in a chipper of the paper industry or produced by mechanical hogs, hammermills, etc;

Flake means a small wood particle of predetermined dimensions, specifically produced by specialized equipment of various types. Each flake is essentially flat, of uniform thickness and has the grain of the wood running essentially in the plane of the flake;

Shaving means a small wood particle of indefinite dimensions developed incidental to certain woodworking operations involving rotary cutterheads turning in the direction of the grain; because of this action, a thin curled particle of varying thickness is obtained, usually feathered along at least one edge and thich at another edge;

Sliver means a small wood particle of nearly square or rectangular cross-section with a length parallel to the grain of the wood at least 4 times the thickness;

Strand means a speciallized wafer having a length at least twice the width;

Wafer means a specific type of wood flake produced as a primary fuction of specialized equipment (ie, waferizer) and having a controlled length of at least 30 mm alomg the grain direction, a controlled thickness and a variable or controlled width. Each wafer is essentially flat and has the grain of the wood running predominanatly in the plane of the wafer. In overall character wafers resemble small pieces of thin veneer. Wafers may be purposely produced with a narrow width to facilitate alignment.

structural and construction uses in North America since 1962, including use as wall and roof sheathing, sub-flooring underlayment, exterior cladding and soffits and for residential, farm and industrial buildings. They are not generally intended for use in the furniture manufacturing industry.

Because of the fairly narrow definition given for waferboard and strandboard, and their relatively recent appearance on the marketplace outside of Canada, not a great deal of literature is available dealing specifically with dimensional stabilization of these boards. Therefore the literature search was expanded to include the terms 'particleboard' and 'flakeboard', with the understanding that problems of dimensional stability should be similar for all wood products made with wood particles. Articles dealing specifically with waferboard and oriented strandboard have been highlighted.

2.0 Methods for Determining Dimensional Stability

Dimensional stability measurements are broken into two components

1) Linear Expansion - the changes in dimension measured in the plane of the board,

and 2) Thickness Swell - the changes in dimension measured perpendicular to the plane of the board.

Changes in the thickness of the board due two changes in moisture content, are generally one or two orders of magnitude greater than changes in the linear dimensions of the board. Table 2 summarizes the Grade Property Requirements for Waferboard and Oriented Strandboard as outlined in Canadian Standard CAN3-0437.0-M85. Similar requirements are also set by agencies in other countries such as the National Particleboard Association in the U.S.A.

Linear expansion across the panel width is significant for construction panels, as excessive expansion may cause buckling. In the Canadian Standard, linear expansion is measured by two methods 'Oven Dry to Saturated' and '50-90% Relative Humidity'. Excessive thickness swell of panels is associated with a decrease in density of the panel and a subsequent loss in the strength properties. Thickness swell is measured by 'Twenty-Four Hour Soak'. These methods have been summarized in Table 3.

Other important test methods have been established by ASTM, the American Society for Testing and Materials, and the American Plywood Association.

Table 2

Grade Property Requirements
(Average Values for a Sample Consisting of Five Panels) *

Property	Limit	Units	Direction†	R-1	O-1	O-2
Thickness Swell–24 h soak–12.7 mm or thinner	Max	%		25	25	25
–thicker than 12.7 mm				20	20	20
Linear Expansion–oven dry to saturated	Max	%	∥	0.40	0.40	0.40
			⊥	0.40	0.40	0.40
Linear Expansion–50–90% rh	Max	%	∥	0.20	0.20	0.20
			⊥	0.20	0.20	0.20

* In addition no individual panel in the five panel samples shall exceed the limits by more than 20%

† For Type R(random) board, ∥ means parallel to the longer dimension of the board; ⊥ means perpendicular to the longer dimension.

For Type O(alligned) board, ∥ means parallel to the indicated direction of face alignment; ⊥ means perpendicular to the indicated direction of face alignment.

Table 3

Test Methods for Determining
Dimensional Stability

Linear Expansion	
Oven Dry to Saturated	Specimens shall be initially dried at 103°C for 24h or until constant weight is attained. After drying the specimens shall be wrapped in polyethylene and allowed to cool to 21°C. Following dry gauge measurements, the specimens shall be submerged in water at 18°C and subjected to a vacuum of 92±6 kPa for 1 h. The specimens shall then be subjected to pressure at 620±6 kPa for 2 h.
50 to 90% Relative Humidity	Specimens shall be initially conditioned to constant mass at 50% relative humidity and 21°C. Following guage length measurements, the samples shall be reconditioned to constant mass at 90% relative humidity and 21°C.
Thickness Swell	
Twenty-Four Hour Soak	Specimens, after initial measurments, shall be submerged horizontally under 25 mm of clear water maintained at a temperature of 21°C for 24 h. They shall then be removed and suspended to drain for 10 min before measuring.

ASTM D1037 covers the standard methods of 'Evaluating the Properties of Wood Base Fiber and Particle Panel Materials'. In this Standard, linear expansion is measured at sample equilibrium over a change in relative humidity from 50-90% at 20 C or alternatively from 30-90% at 20 C. The sample is assumed to have reached equilibrium when it is neither losing nor gaining more than 0.05% weight in a 24 hour period.

Water absorption and thickness swell are measured on 304x304 mm or 152x152 mm samples that have been conditioned to 65% relative humidity at 20 C and then submerged under 25 mm of water at 20 C. Samples are measured after 2 and 24 hours submersion and subsequently oven dried to determine water absorptions.

A third ASTM procedure frequently used for measuring irreversible thickness swell as well as the strength properties intended, is Accelerated Aging. Test samples are subjected to 6 complete cycles of accelerated aging, where each cycle consists of the following steps

1) Immerse in water at 49 C for 1 hour
2) Expose to steam and water vapor at 93 C for 3 hours
3) Store at -12 C for 20 hours
4) Heat at 99 C in dry air for 3 hours
5) Expose to steam and water vapor at 93 C for 3 hours
6) Heat in dry air at 99 C for 18 hours.

After the completion of six cycles the sample is reconditioned to 65% relative humidity and 20 C for at least 48 hours.

Other popular methods used by researchers to determine the dimensional stability behavior of panels during exposure to varying moisture environments include

* water soaking and exposure to different relative humidity levels for up to 2 months,
* exposure to hot or boiling water for different lengths of time
* cycling samples between oven dry (OD) and water soak (WS) or OD and boiling, and
* cycling samples between different levels of relative humidity.

In order to reduce the time required to perform the standard tests, many of which require approaching equilibrium, the Forest Products Laboratory in Madison Wisconsin developed a Vacuum-Pressure Soak test method commonly referred to as VPS. In this method matched samples 19x560 mm are measured and weighed at room temperature. One sample is then placed in an oven at 104 C for 22 hours while the second sample is exposed to a pressure of at least 27 kPa below ambient for 30 minutes. Without releasing vacuum the sample is then submerged in water at room temperature and subjected to water pressure of at least 276 kPa for 22 hours. After treatment, both samples are remeasured at room temperature.

This method was reported by Heebink (1967) who found that water absorption was very close to that observed during one month water soak trials. Linear expansion and thickness swell were consistently lower than after one month of water immersion but the order determined by

linear movement of different samples was the same.

One of the major problems in testing samples for changes in dimension is the great length of time required for samples to approach equilibrium. Johnson (1964) showed changes were still apparent up to 2 months after exposure to different relative humidities and water soaking began. Although it is possible to draw curves showing the relationships between thickness swell or linear expansion and water absorption, some authors (Vital 1980, Lehmann 1972) have found water absorption and dimensional changes are also both highly correlated to time. As illustrated in Figure 2, others (Jorgensen and Odell 1961, Suchsland 1972) have shown strong hysteresis exists in the absorption/desorption isotherms of panel products. Where pronounced hysteresis occurs, the effect will be to increase the observed values of irreversible swelling and decrease the amount of reversible swelling and panel history may influence reported results.

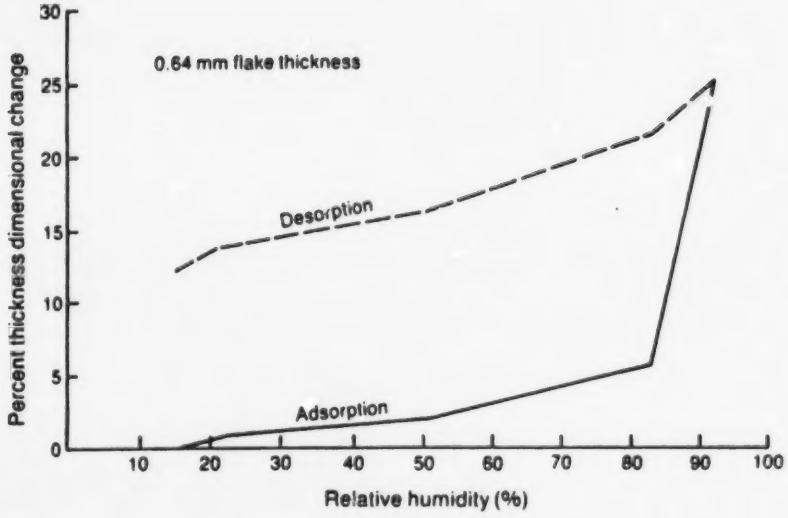

Figure 2: Adsorption/desorption isotherm for an oak flakeboard. (Drawing after Jorgensen and Odell, 1961)

3.0 Normal Process Variables

Normal process variables are those process variables that would have to be considered in essentially all panel product manufacturing plants. The dimensional stability of reconstituted wood panels is influenced by the choice of normal process variables such as wood species, particle geometry, board density, resin type, resin level, blending efficiency and pressing conditions such as time, temperature and closure rate. Despite the reasonably large amount of information available in the literature, it is frequently difficult to directly compare results from different sources due to the large number of variables, their interactions and the different methods used to measure reversible thickness swell, irreversible thickness swell and linear expansion.

Several useful review articles on dimensional stability of reconstituted wood panels, discussing both normal process variables and special treatments, are those by Neusser (1965), Halligan (1970), Paulitsch (1975), Kelley (1977) and Kollmann (1978).

3.1 Density

The variation of dimensional stability with board density has been one of the most widely studied normal process variables. For a given wood furnish, an increase in board density implies a higher level of compression set and this would be expected to give higher swelling as stresses are relieved. However , higher panel densities are also associated with lower water absorption and water absorption rates, and

this may influence swelling results on tests that are terminated before swelling equilibrium has been reached.

The majority of researchers have found thickness swelling increases with increasing board density, however this finding is not unanimous. Several authors have found little correlation or even a decrease in thickness swelling with increased board density. Table 4 summarizes the trends found in dimensional stability/density behavior by various investigators for both thickness swelling and linear expansion.

Gerard (1966) conducted fundamental studies with respect to compression, moisture and temperature on simulated particle board constructions of aspen. Parallel ply assemblies of 76x76x2 mm aspen flakes and cross ply assemblies of 76x10-38x2 mm aspen flakes were compressed at three levels (20, 40 and 60%), at three temperatures (27, 93 and 160 C) and at three mat moisture contents (4, 8 and 12%). No resin or other binder was used.

The dimensions of each ply were measured after pressing, after 48 hours of soaking and after redrying at room temperature. The author found that while cold pressed assemblies experienced an even degree of compression throughout the assembly, temperature gradients established during hot pressing led to increased compression of the hot outer layers relative to the cooler inner layers. High mat moisture content also increased the dimensional changes that occurred during pressing. Figure 3 shows the changes in dimension during pressing, soaking and redrying for mats with 8% moisture compressed to 60% at room temperature

Table 4

Reported Results of the Effect of Increasing Board Density on Dimensional Stability

Thickness Swelling			
Increase	No Effect	Decrease	Inconsistent Results
Gatchell et al.(1966)[1,2]			Turner(1954)[4]
Heebink and Hefty(1969)[3]			
Stewart and Lehmann(1973)[1,2]			
Gertjejansen et al.(1973)[1]		Stewart and Lehmann(1973)[2]	
Lehmann(1974)[3]	Lehmann(1974)[1]	Lehmann(1974)[2]	
Hse(1975)[1,3,4]		Vital et al.(1975)[1,2]	
Greubel and Paulitsch(1977)[1]			
Rice and Carey(1978)[2,3]	Place and Maloney(1977)[2]		
Vital et.al(1980)[1]			Gertjejansen et al.(1980)[1,3]
Geimer(1982)[1]			
	Price and Hse(1983)[4]		
	Brink(1983)[4]		
	Kelly and Price(1985)[1]		
Panning and Gertjejansen(1985)[4]			Kelly and Price(1985)[3,4]

Test Methods
1 – relative humidity exposure
2 – water soak tests
3 – OD-VPS
4 – other test method

Table 4 (continued)

Reported Results of the Effect of Increasing Board Density on Dimensional Stability

Linear Expansion

Increase	No Effect	Decrease	Inconsistent Results
			Turner(1954)[4]
Gatchell et al.(1966)[1,2]			
Stewart and Lehmann(1973)[2]	Stewart and Lehmann(1973)[1]		
Lehmann and Hefty(1973)[3]	Lehmann and Hefty(1973)[1]		
	Gertjejansen et al.(1973)[1]		
Lehmann(1974)[3]	Lehmann(1974)[1,2]		
	Lehmann and Boone(1975)[1]		
Hse(1975)[1,3,4]			
Greubel and Paulitsch(1977)[1]			
			Gertjejansen et al.(1978)[1,2,4]
Vital et al.(1980)[1]			
Geimer(1982)[3]	Geimer(1982)[1]		
Price and Hse(1983)[4]		Price and Hse(1983)[4]	
Brink(1983)[4]			
	Kelly and Price(1985)[1]		Kelly and Price(1985)[3]

Test Methods
1 – relative humidity exposure
2 – water soak tests
3 – OD-VPS
4 – other test method

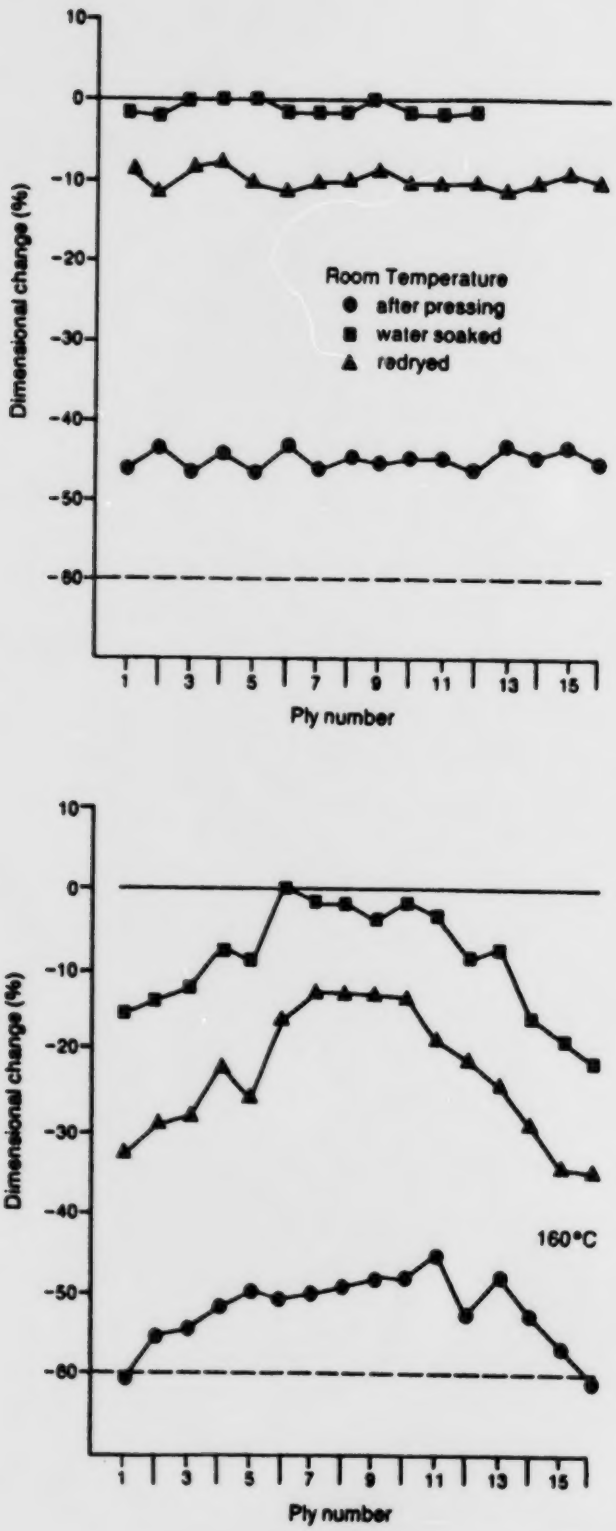

Figure 3: Dimensional changes in aspen ply assemblies pressed at room temperature and 160 C. (Drawing after Gerard, 1966)

and at 160 C.

Particles exposed to higher levels of compression experienced greater swelling as a result of soaking, greater compression retained after swelling and greater reshrinking on redrying. Particles increased in width as a result of increased compression, with inner particles experiencing the greatest increases. However, outer particles still experienced the gratest linear swelling on soaking.

Swelling due to soaking of the highly compressed particles was much greater than the normal swelling of aspen. Gerard concluded that variation in conditions of temperature, moisture content and degree of compression throughout real particle board during pressing will lead to variations in adhesion and recovery effects throughout the particleboard.

3.1.1 Thickness Swelling

Turner (1954) studied particleboards made from a wide range of particle shapes and over a range of density from 500 to 1050 kg/m^3. Thickness swell was measured after two water soak-oven dry cycles. Within a particle class and resin level, the raw data do not show a consistent trend with density and the author did not analyse thickness swell data with respect to density.

Several authors recognized the effect of density on dimensional

stability and corrected their results for this variable but did not report what effect was found or the corrections that were made (Brumbaugh 1960, Post 1961. Jorgensen and Odell 1961).

Gatchell, Heebink and Hefty (1966) varied the density of 6% PF bonded Douglas fir particleboard from 480 to 800 kg/m^3. Thickness swell was measured from oven dry to various relative humidities and to water soak. Density effects became important above 80% relative humidity with thickness swelling increasing with increasing density. In one year exposure tests, 640 kg/m^3 boards showed less thickness swell at all of the sites than either 480 or 800 kg/m^3 boards. In accelerated aging tests 480 kg/m^3 boards had thickness swells of 10% against 32% for 800 kg/m^3 boards.

Heebink and Hefty (1969) found increasing board density from 480 to 960 kg/m^3 in 6% PF bonded Douglas fir particleboards increased thickness swell from 20 to 40% for untreated boards and from 11 to 23% for steam treated boards. Thickness swell was measured after 1 cycle of OD-VPS. Irreversible thickness swell increased from 5.2% to 21.1% for untreated boards and from -1% to +6.2% for steam treated boards over the same range in board density.

Stewart and Lehmann (1973) studied the effect of three panel densities (560, 640 and 760 kg/m^3) on particleboards made from cross-grain planed hardwood flakes. Thickness swell was measured during relative humidity exposures from 0-90% and 30-90%, and 24 hour and 30 day water soak tests. Of the four wood species studied, thickness swell increased with

density in relative humidity tests for all species except basswood where high density boards were more stable (range : 7.4-14.6%). In the water soak tests, basswood was most stable at high density, hickory and poplar were most stable at low density and red oak was most stable at high density for the 24 hour test and most stable at low density for the 30 day test. Thickness swell data ranged from 11% to 28% for the 24 hour water soak test and from 27% to 39% for the 30 day water soak test. The authors concluded there was a definite interaction between board density and species type.

Lehmann (1973) investigated densities of 650 and 750 kg/m^3 in UF bonded Douglas fir particleboards. Thickness swell was measured at various relative humidity exposures and one OD-VPS test. Panel density had no effect on thickenss swell during relative humidity tests. Density only affected thickness swell during OD-VPS tests at the 2% resin level where thickness swell increased from 40% to 60% as density increased from 650 to 750 kg/m^3.

Gertjejansen et al. (1973) studied 4% PF bonded particleboards at three density levels (610, 690 and 770 kg/m^3). Averaged over all of the species mixtures studied, thickness swell increased from 23% to 31% and irreversible thickness swell increased from 15% to 32% as board density increased from 610 to 770 kg/m^3, after one cycle from 50% relative humidity - VPS - 50% relative humidity. This trend was consistent over all of the species studied.

Lehmann (1974) studied 600 and 680 kg/m^3 PF bonded Douglas fir

flakeboards. Panel density had varied effect, with generally more stable boards at high density after the 24 hour water soak and reversing this trend in the 30 day watersoak and OD-VPS tests. There was little effect of panel density in the 50-90% and 30-90% relative humidity tests with only a slight decrease in thickness swell at increasing panel density. Irreversible thickness swell determined after accelerated aging tests also increased at higher density. Overall, thickness swell ranged from 10-18% during relative humidity tests, from 10-40% for 24 hour soak, from 22-47% for 30 day water soak and from 25-49% for OD-VPS. Irreversible thickness swell ranged from 16-53% after accelerated aging.

Vital, Lehmann and Boone (1975), using particleboards made from 4 exotic hardwood species with densities from 280 to 650 kg/m^3, studied the relationship of board density to species density on dimensional stability properties. Two compression ratios (board density/species density = 1.2 and 1.6) were studied using all possible mixtures of 1, 2, 3 and 4 species. Thickness swell was measured during 30-90% and 50-90% relative humidity exposure tests and 24 hour soaking. All single species showed decreased thickness swelling with increased density in the 24 hour water soak except the lowest density species. Increase in thickness swell with density also occurred for 2 of the two species mixtures, both containing the lowest density species, and on the four species mixture. The range in thickness swell during the 24 hour water soak was 4-37%. In the 30-90% relative humidity exposure, boards made with the single species of two lowest densities, 1 two species mixture and the four species mixture showed increases in thickness swell with increasing density, the remaining 11 mixtures showed the opposite

behavior. During the 50-90% relative humidity exposure only the lowest density species showed increased thickness swell with density. Thickness swell ranged from 6-15% during the relative humidity tests.

Increased density is always associated with decreased moisture absorption, thus on the time limited tests, such as the 24 hour soak, thickness swell may be limited by slow water absorption. The length of time required for the relative humidity exposure tests was not reported by the authors. The authors also suggested that high specific gravity may have resulted in a closer approach to maximum glue bond strength and high moisture content during pressing, resulting in increased compressive sets.

Flakeboards of three densities (630, 710 and 790 kg/m^3) from 9 hardwood species (density range : 480 to 760 kg/m^3) were studied by Hse (1975). Thickness swell was measured by 50-90% relative humidity exposure, 5 hour boil and VPS. The 5 hour boil gave consistently higher thickness swell results (range : 21-112%) and thickness swell increased consistently with density. VPS data (range : 20-57%) showed the same trend. Results from the 50-90% relative humidity tests were not as dramatic (range : 13-25%) and only showed an increase in thickness swell with density when board density changed from 710 to 790 kg/m^3.

PF bonded particleboards in the density range from 500 to 800 kg/m^3 were studied by Greubel and Paulitsch (1977) who measured thickness swell when boards were exposed to changes in relative humidity from 65% - 30% - 90% at 20 C. During the change from 65 - 30% relative humidity,

thickness swelling was found to be dependent on both density and press temperature with no great effect of density apparent for low press temperature and decreased thickness stability with increased density for high press temperature. Thickness stability was best at low density for the change in relative humidity from 30-90% (range : 7-13%). According to the authors, increased density causes a decrease in the voids between particles thus reducing the possibility for wood particles to expand within the board itself.

Place and Maloney (1977) studied PF bonded composite bark-flakeboards and found thickness swell after 24 hour water soak was not a function of density.

Rice and Carey (1978) investigated variables related to compression and crushing as they affect the permanence of panel consolidation. Wood from four species of diffuse porous, uniform textured, medium pH hardwoods (density range : 330 to 660 kg/m^3) was used to make boards with densities of 560, 680 and 800 kg/m^3. This corresponded to a range in compaction ratios of 0.94 to 2.43. Thickness swelling was measured after 1 and 7 days of water submersion and after the 1st and 6th cycle of VPS - boil - dry procedure (WCAMA accelerated aging test). During the water soak tests some increase in thickness swelling was noted with increased density, especially at low resin content (range: 15-55%). This effect was more pronounced after the 6 cycle accelerated aging test (range 20-100%). These results were then correlated with compaction ratio. As shown in Figure 4, accelerated aging thickness swell

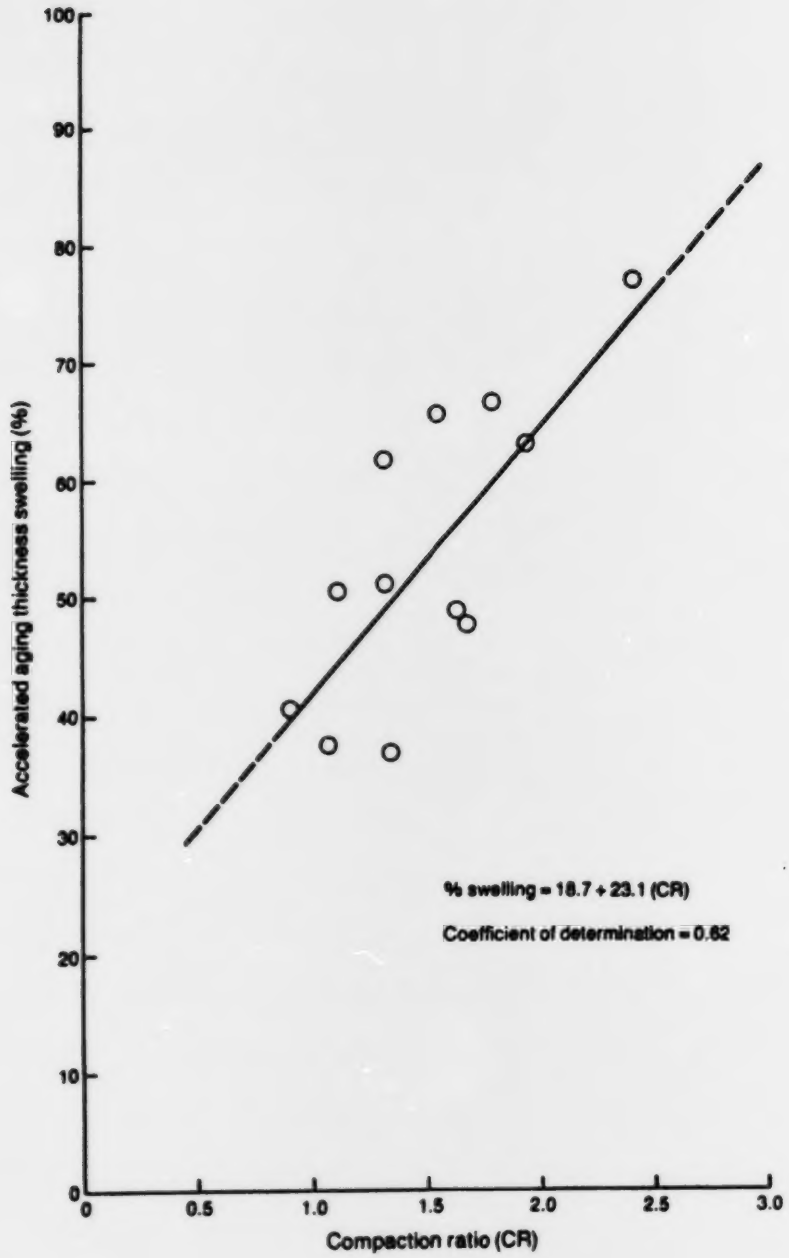

Figure 4: Accelerated-aging, thickness swelling results (WCAMA six cycle test) shown as a function of compaction ratio. (Drawing after Rice and Carey, 1978)

increased over the range of compaction ratios studied. Thickness swell results after room temperature soaking did not show a clear dependence on compaction ratio.

Gertjejansen (1980) found no consistent effect between density (670 and 770 kg/m^3) and thickness swell measured during relative humidity exposures from 50-90%, 24 hour water soak or accelerated aging, for particleboards made from Philippine hardwood mixtures.

Vital et al. (1980) established equations predicting thickness swell in particleboard and flakeboard based on measurements of Douglas fir boards over the specific gravity range from 530 to 780 kg/m^3. Multiple regression analysis was used to select the best set of variables. In flakeboard, density appears in the term SGxWA (specific gravity x water absorption), showing the important interaction that exists between these two terms in determining thickness swelling behavior. In particleboard, the effect of density on thickness swell depended on the relative humidity - at low relative humidity, thickness swell was independant of board density and at high relative humidity, thickness swell increased as board density increased.

Geimer (1982) manufactured 5% PF bonded Douglas fir flakeboards in such a manner as to produce boards without significant density gradients. These boards were made at 4 density levels (480, 640, 800 and 960 kg/m^3) and compared to boards manufactured with normal density gradients. Dimensional stability was measured by progressively subjecting the samples to the following relative humidity conditions : oven dry

(102 C, 24 hours), 30% (room temperature, 77 days), 50% (room temperature, 41 days), 90% (room temperature, 32 days), VPS (30 minutes under water at a pressure 17 kPa below ambient, 20 hours underwater at 415 kPa) and OD (102 C for 24 hours). Sample thickness was determined at the end of each exposure.

Geimer found that to predict the thickness swell for flakeboards exposed to relative humidities with equilibrium moisture content below the fiber saturation point, both specific gravity and moisture content were required. This was because both equilibrium moisture content and equilibrium thickness swell are independently time dependent on specific gravity and exposition conditions. Equilibrium thickness swelling is therefore not necessarily reached at the same time as equilibrium moisture content. One investigator (Liiri, 1962) showed that boards with a density of about 700 kg/m^3 reached eqilibrium moisture content at 95% relative humidity in 30-40 days but gained an additional 3.5% in thickness during the next 100 day period.

Figure 5 shows the relationship found by Geimer between thickness swell, moisture content and density. At any given level of moisture content, thickness swell was greatest at the highest density, however at any one level of humidity exposure, thickness swell was less in the boards with high density. Between 90-100% relative humidity, both equilibrium moisture content and thickness swell changed considerably and at different rates. Fiber saturation moisture content was between 20 and 30% and considerable irreversible thickness swell occurred. At these high moisture content levels, thickness swell could be predicted using

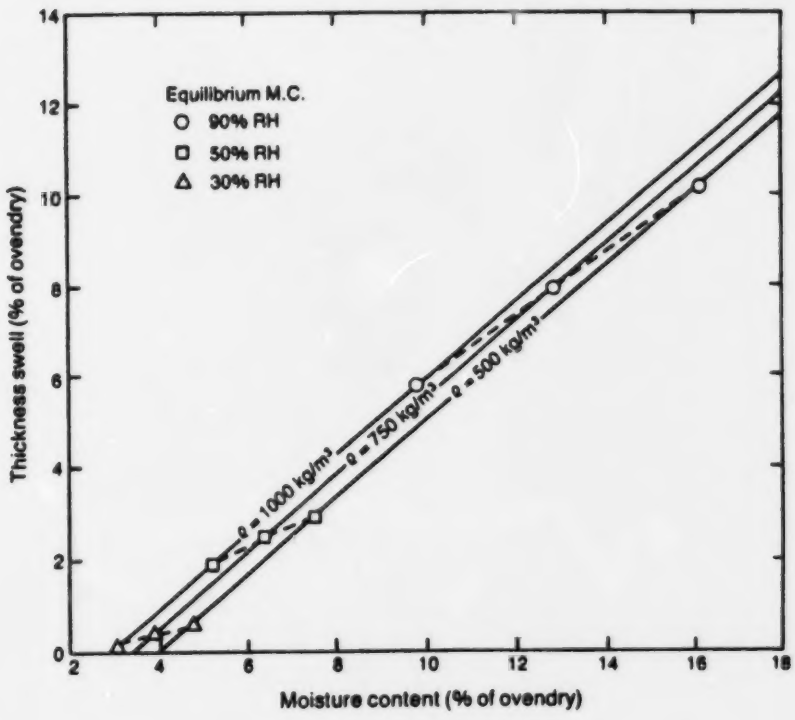

Figure 5: Thickness swelling of flakeboard at three equilibrium moisture content levels. (Drawing after Geimer, 1982)

density as the single variable, and thickness swell increased with increasing board density.

The release of compression sets (irreversible thickness swell or 'springback') accounted for almost all of the difference in total thickness swell caused by changes in density for boards exposed to VPS. This is illustrated in Figure 6. The author then used the equations developed for single density boards in conjunction with density gradient data to prodeict the behavior of real boards. Predicted results lay in the range of 68 to 120% of the actual values.

Price and Hse (1983) made 5.5% PF bonded flakeboards at two density levels (overall range : 625 to 720 kg/m^3) from 13 mixtures of 7 bottomland hardwood species. Thickness swell was measured following an OD-VPS procedure (APA Test Method P-1). Eight of the species mixtures showed less than 1% change in thickness swell with density (thickness swell range : 22-35%), two showed increases of about 2% (low density thickness swell range : 18.5-26%) with increases in density and three showed decreases of about 4% with an increase in density (low density thickness swell range : 30-41%).

Brink et al. (1983) found little effect of density on thickness swelling over the density range 450 to 850 kg/m^3 after a 2 hour boil test with all results between 14-16%. These boards had been made with an oxidative pretreatment and a cross linking agent. The excellent dimensional stability was thought to indicate covalent type bonding was achieved.

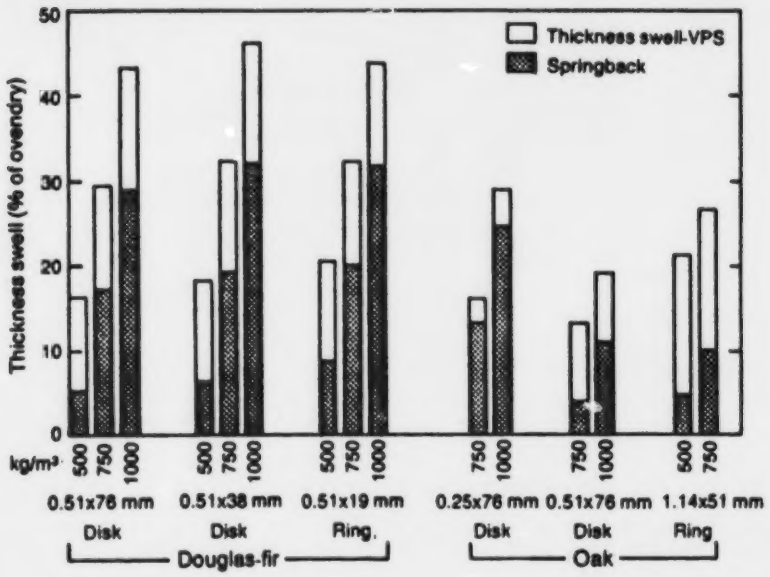

Figure 6: Thickness swell and springback following a vacuum-pressure soak treatment. (Drawing after Geimer, 1982)

Kelly and Price (1985) compared purchased commercial waferboard with 5.5% PF bonded flakeboard panels made with 4 southern hardwoods, southern pine and a mixture thereof. Panel density was varied from 560 to 790 kg/m^3 with waferboard density at 680 kg/m^3. In the relative humidity exposure from 50-90% there was no significant effect of panel density on thickness swell with experimental panels ranging from 16% to 35% and waferboard at 20%. There was no consistent increase in thickness swell within a species as density increased for either the OD-VPS test (range: 33-75%, waferboard 37%) or weatherometer exposure (range: 47-100%, waferboard 4%).

Panning and Gertjejansen (1985) evaluated waferboards made with 3% PF resin and mixtures of aspen, balsam poplar and paper birch. Over the density range studied (560 and 640 kg/m^3) thickness swelling and irreversible thickness swelling both increased after 2 hour boil and subsequent reconditioning. Figure 7 shows that slopes of the regression lines appear parallel to the 'standard' aspen waferboard. For low density waferboards, thickness swell ranged from 17-32% against 25-44% for the high density boards. Irreversible thickness swell increased from 8-18% to 14-25% for the same changes in density.

3.1.2 Linear Expansion

Although Turner (1954) measured linear expansion on boards made from a wide variety of particle shapes and over a density range from 500 to

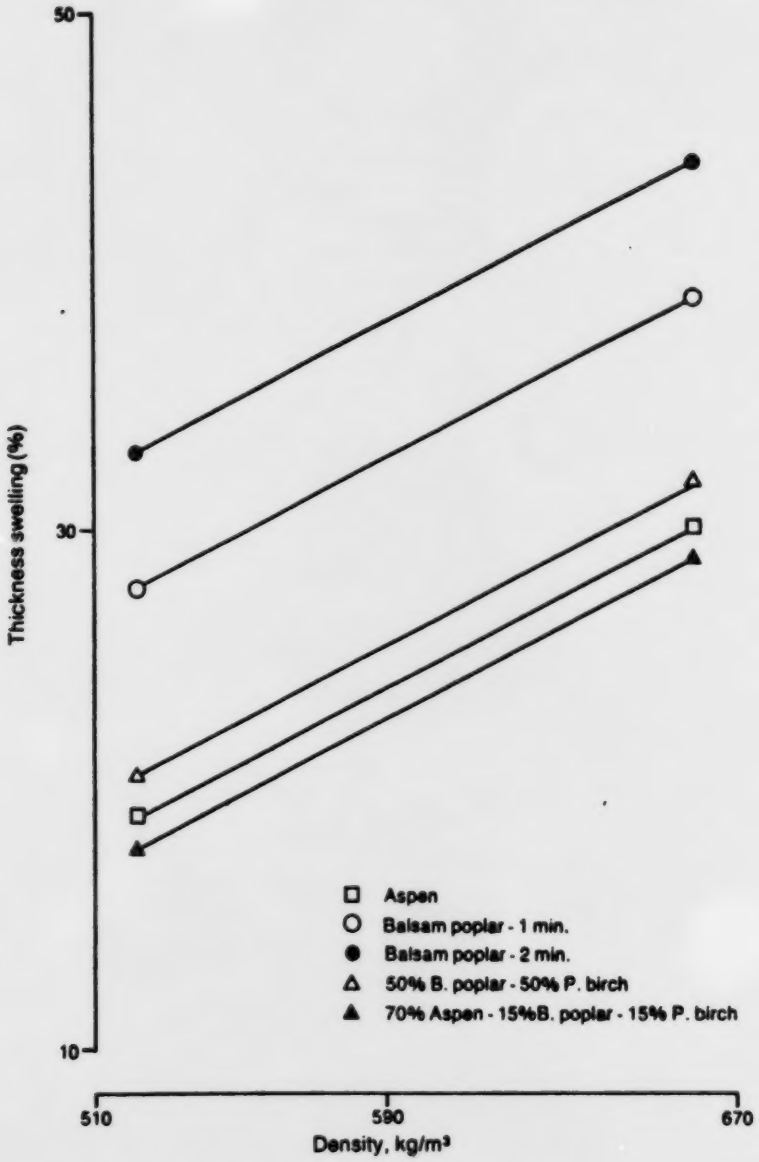

Figure 7: Regression lines of thickness swelling after aging as a function of density. (Drawing after Panning and Gertjejansen, 1985)

1050 kg/m^3, he did not analyse the data for possible correlation between these two variables. No consistent trend is apparent in the raw data.

Gatchell, Heebink and Hefty (1966) investigated changes in linear dimension on Douglas fir particleboards with densities of 480, 640 and 800 kg/m^3. Linear expansion was measured during exposures to various relative humidities and to a 30 day water soak. Linear expansion increased slightly with density between the 640 and 800 kg/m^3 boards over all humidity exposures. All linear expansion measurements were between 0.16% (low density board at 30% relative humidity) and 0.40% (high density board afer 30 day water soak).

The effect of three panel densities 560, 640 and 720 kg/m^3) on linear expansion of particleboards made from cross-grain planed flakes of 4 hardwood species, was studied by Stewart and Lehmann (1973). Linear expansion was measured during relative humidity changes from 0-90% and 30-90%, and 24 hour and 30 day water soak tests. The only significant density effects were apparent in the 30 day water soak where boards made from the two low density species were more stable at high density and boards made from the high density species were more stable at low density. Overall range in measured linear expansion values was 0.08% (Basswood, 30-90% relative humidity) to 0.41% (Red Oak, 30 day water soak).

Lehmann (1973) studied UF bonded Douglas fir particleboards with densities of 650 and 750 kg/m^3. Linear expansion was measured at various relative humidity levels and one OD-VPS test. There was no

significant effect of density on linear expansion in relative humidity tests. At low resin content (2%) during the OD-VPS test, linear expansion increased from 0.66% to 0.90% as density increased from 650 to 750 kg/m^3. Otherwise linear expansion ranged from 0.19% to 0.58%.

Gertjejansen et al. (1973) studied 4% PF bonded wafer-type particleboards at three density levels (610, 690 and 770 kg/m^3). Averaged over all of the species mixtures studied, linear expansion showed no trend with change in density. The overall range in linear expansion, as measured from 50% relative humidity to VPS was 0.123% to 0.305%, with both values occurring in intermediate density boards.

Lehmann (1974) investigated PF bonded Douglas fir particleboards with densities of 600 and 680 kg/m^3. Linear expansion was measured in 30-90% relative humidity exposure, water soak and OD-VPS tests. Density had almost no effect on linear expansion during the relative humidity test or water soak tests (range: 0.01-0.32%). Linear expansion increased only slightly (from 0.27% to 0.28% , averaged over all the other variables) as density increased during the OD-VPS test.

The effect of compression ratio (board density/wood specific density) linear expansion was investigated by Vital, Lehmann and Boone (1975) using UF bonded particleboards made from mixtures of four exotic hardwood species with densities ranging from 280 to 650 kg/m^3. Linear expansion was measured during 30-90% and 50-90% relative humidity tests and 24 hour water soak. The authors found no linear relation between linear expansion and density, but linear expansion was affected by

density when each board type was considered separately. Results varied among board type and test procedure. None of the boards showed decreases in linear expansion with increased density in the 50-90% relative humidity tests, 2 out of 15 board types showed decreases in linear expansion with increases in density in the 30-90% relative humidity tests and 8 out of 15 board types showed significant decreases in linear expansion (of 40-60%) with increases in density for the 24 hour water soak. During the 24 hour water soak, the range of linear expansions measured was 0.09% to 0.31%.

PF bonded flakeboards were manufactured from 9 hardwood species (density range: 480 to 760 kg/m^3) at three levels of density (630, 710 and 790 kg/m^3) by Hse (1975). Linear expansion was measured after 50-90% relative humidity exposure, 5 hour boil and VPS tests. In all of the tests, 790 kg/m^3 boards expanded more than the lower density boards except for hickory and post oak. The greatest range in linear expansion was measured during VPS tests where results varied from 0.027% (710 kg/m^3 red maple) to 0.480% (790 kg/m^3 white oak).

Greubel and Paulitsch (1977) measured linear expansion of PF bonded particleboards with densities from 500 to 800 kg/m^3 when exposed to changes in relative humidity from 65% - 30% - 90% at 20 C. In both relative hummidity changes, linear stability was best at low density. Measured linear expansions in the 30-90% relative humidity test ranged from 0.185% (low density, low resin level) to 0.235% (high density, high resin level).

Gertjejansen et al. (1978) found no consistent relationship between density level (670 and 770 kg/m^3) and linear expansion measured from 50-90% relative humidity, 24 hour water soak or accelerated aging, from particleboards made from Phillipine hardwood mixtures.

Vital et al (1980) established equations to predict linear stability in particle- and flakeboards, based on measurements of Douglas fir boards over the density range from 530 to 780 kg/m^3. Multiple regression analysis was used to select the best set of variables. Because of the strong interaction of the variables with both linear expansion and water absorption, linear expansion was most easily explained in terms of the hygroexpansivity ratio - Linear Expansion/Water Absorption (LE/WA). For flakeboard, LE/WA increased with an increase in specific gravity (SG) and an increase in the product SG$\times\Delta$RH (ΔRH = change in relative humidity). LE/WA of particleboard was also found to increase with increases in SG.

Flakeboards without density profiles were manufactured at four density levels (480, 640, 800 and 960 kg/m^3) from 5% PF bonded Douglas fir flakes by Geimer (1982). Linear expansion was measured on samples exposed from oven dry to progressively higher relative humidities, VPS and subsequently redried. The effect of density on linear expansion was only significant after VPS treatment and not during the increases in relative humidities. Consistent relationships describing the effect of specific gravity on linear expansion following reconditioning to oven dry were not obtained.

Price and Hse (1983) made 5.5% PF bonded flakeboards at two density levels (range : 625 to 720 kg/m^3) from 13 mixtures of 7 bottomland hardwood species. Linear expansion was measured following an OD-VPS procedure (APA Test Method P-1). In Phase I, panels made with a mixture containing all of the species showed some decrease in linear expansion with increased density for panels with equal core and face flake lengths. There was a slight increase in linear expansion with increased density for boards with longer face than core flakes. All linear expansion measurements were less than 0.22%. In Phase II, 10 of the 13 species mixtures showed increased linear expansion with increased density. The range of linear expansions measured was 0.081% to 0.41%.

Brink et al. (1983) did not comment on the effect of density on linear stability of boards made by using an oxidative pretreatment and a cross-linking agent. Raw data indicate a slight increase in linear expansion with an increase in density from 660-770 kg/m^3. All of the linear expansion values were between 0.080% and 0.250% after a 2 hour VPS treatment.

Kelly and Price (1985) compared 5.5% PF bonded flakeboard panels made from 4 southern hardwoods, southern pine and an all species mixture with purchased commercial waferboard. Density had no significant effect on linear expansion within any species during 50-90% relative humidity exposure. Linear expansions were all between 0.002% and 0.044% during this test, except for white oak which had linear expansion of about 0.18% and waferboard at 0.2%. During OD-VPS test, linear expansion showed no consistent trend with density and values for the experimental

panels ranged from 0.13% to 0.31% except for white oak where linear expansion was 0.47% compared with 0.39% for waferboard.

3.2 Particle Geometry

Particle size and shape were some of the earliest parameters thoroughly investigated. General trends noted by most investigators include better thickness stability for thin flakes over thick flakes, and long flakes over short flakes. Some investigators have used the concept of slenderness ratio to correlate results. Thin, long flakes appear to be the best wood furnish for reduced linear expansion.

3.2.1 Thickness Swelling

Turner (1954) studied phenolic bonded wood panels made from particles in the form of flat flakes, thin strands, helical ribbons and cubes. Irreversible thickness swell was measured after two water soaking/oven drying cycles. For those boards made with particles that had undamamged fiber structure, particle shape was not as important as resin content in determining thickness stability. Cube based boards, where fiber structure was severly damaged, disintegrated during testing. Of the large particles, helical ribbons gave the least thickness swell (average: 45%) due to the fact that the grain direction in the particles varies in the thickness dimension of the boards as well as in the plane of the board. For the flat flakes (average: 60%), no significant difference was observed for the two flake lengths studied (38 and 76 mm).

Heebink (1955) made boards from 6 types of particles of northern red oak and measured thickness swell after a 24 hour soak as well as after 2

months of conditioning at various relative humidities. Figure 8 illustrates that of the flake type particles, the 25 mm flakes produced more stable particleboards than the 6 mm flakes.

Brumbaugh (1960) concentrated studies on Douglas fir flakes of 4 lengths (13, 25 51 and 102 mm) and 4 thicknesses (0.23, 0.30, 0.38 and 0.46 mm). Thickness swelling was measured after 2 and 24 hours water soak. Although flake thickness had no effect after 2 hours, boards made with thin flakes swelled less after 24 hours. Figure 9 illustrates the effects of flake thickness and length on thickness swell. The increased thickness swell observed in boards made with thick flakes was attributed to larger compressive deformation experienced during pressing for a given density. Void spaces are also larger in boards made from thick flakes, thus speeding water penetration into the board. Short flakes have a greater amount of end-grain surface available for rapid water absorption when compared to long flakes. Length/thickness ratios were found useful for correlating the data, but simultaneously changing the length and thickness generates a family of curves rather than just a single surve.

Post (1961) reported the effect of 4 flake lengths (13, 25, 51 and 102 mm) and 4 flake thicknesses (0.15, 0.30, 0.64 and 1.27 mm) on the dimensional stability of oak flake boards. Thickness swelling was determined after 3 cycles between equilibrium at 50% and 90% relative humidity. Increasing flake thickness again increased the irreversible thickness swelling, from less than 4% to greater than 18%, and reversible thickness swell from about 5% to 11%. The use of longer

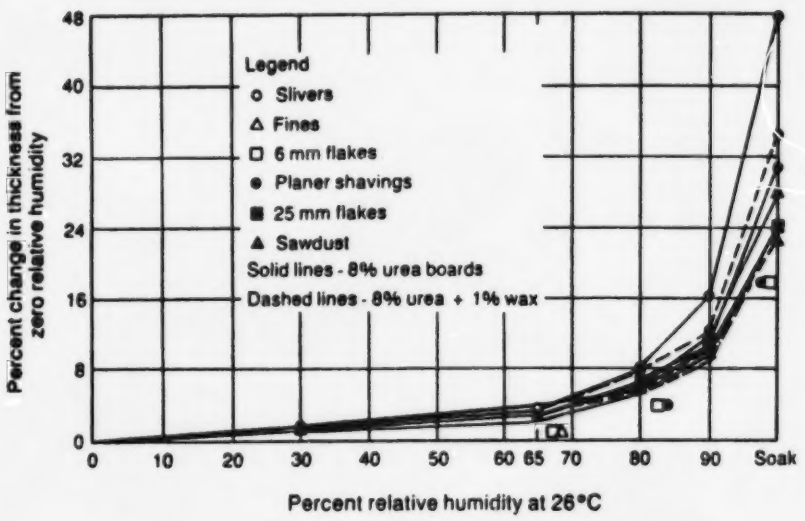

Figure 8: The relation of change in thickness to percent relative humidity. (Drawing after Heebink, 1955)

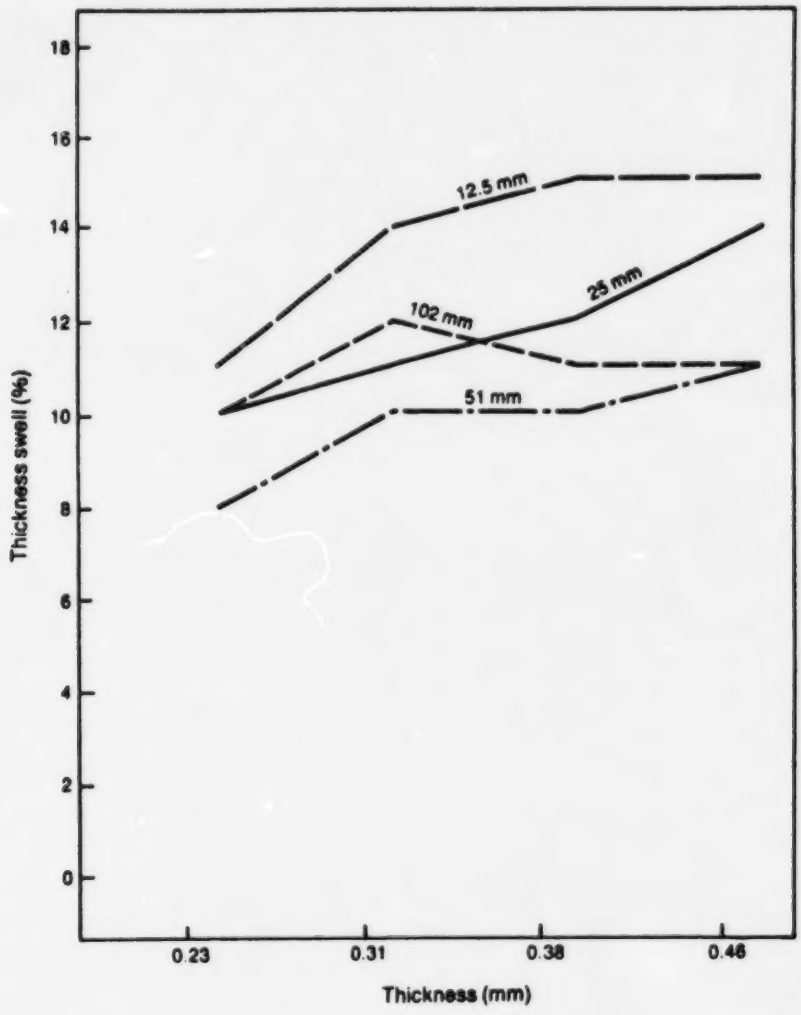

Figure 9: The effect of flake length and thickness on thickness swell after 24 hour water soak. (Drawing after Brumbaugh, 1960)

flakes had little effect when flake thickness was less than 0.30 mm, but decreased irreversible thickness swell from 42-18% and reversible thickness swell from 14-10% on thicker flakes. Jorgenson and Odell (1961), using the same type of boards as Post, studied dimensional changes in the range from 15 to 92% relative humidity. The same trends were observed with respect to particle thickness and length. Boards made with 12 mm long flakes had thickness swells at 92% relative humidity of 10% and 30% for 0.15 mm and 1.27 mm thick flakes respectively.

Gatchell, Heebink and Hefty (1966) varied flake width from a standard 0.38x25mmxrandom width to two additional flake lengths (13 and 51 mm) and two thicknesses (0.18 and 0.76 mm). These additional levels were studied one at a time and not in combination. Specimens were conditioned to equilibrium at various relative humidities and thickness swell increased slightly from 12-15% at 90% relative humidity with an increase in flake thickness from 0.18 to 0.76 mm but was not affected by flake length over the range of flake lengths studied.

Three thicknesses of cross-grain flakes (0.15, 0.30 and 0.46 mm) were investigated by Stewart and Lehmann (1973) in boards made from 4 different hardwood species. Thickness swell was measured after 24 hours and 30 days water soak as well as at various relative humidities between oven dry and 90%. They found no relationship between thickness swell and flake thickness in this case with all thickness swell in the range of 6-13% in 30-90% relative humidity tests.

Work with Douglas-fir flakes of three lengths (13, 25 and 51mm) and two thicknesses (0.76 and 1.14 mm) by Lehmannn (1974) showed no significant effect of flake length on thickness swelling when measured with either water soak or relative humidity exposure tests (average: 12% for 30-90% relative humidity exposure). However, slightly lower thickness swelling was reported for the thinner flakes, especially in the oven dry-vacuum/pressure soak test (33% versus 37%).

Beech (1975) studied the effect of angle cut flakes on thickness swelling properties of phenol formaldehyde bonded particleboards of Scots pine. Boards made with angle cut particles had thickness swells of 7% against 11% for standard particles after 24 hour water soak. Thickness swelling was reduced because the longitudinal direction of the wood grains was slightly oriented in the board thickness. However, these particles also greatly reduced the strength of the board to unacceptable levels.

Geimer, Montrey and Lehmann (1975) made three layer boards from varying proportions of core flakes (19x0.51mmxrandom width) and face flakes (51x0.51x13mm). Thickness swell was measured after an OD-VPS test and irreversible thickness swell was measured after the ASTM accelerated aging test. In general the three layer boards had less total thickness swell (average: 24%) than the all core boards (average: 30%) but irreversible thickness swell (average: 20%) was not improved.

Greubel and Paulitsch (1977) investigated the effect of particle size

distribution on phenol formaldehyde bonded particleboards (particles < 3.5 mm). Boards made with a higher bulk density particle mixture (more fines) had the lowest thickness swelling. The use of fines appeared to reduce the influence of the anisotropic nature of wood and thus reduce thickness swell. Thickness swelling in 30-90% relative humidity exposure was all between 7% and 14%.

Price and Lehmann (1979) described the influence of various flake generating techniques on particle geometry and flakeboard properties. Disk, drum, ring and lathe flakers were used to generate flakes 57x0.5mmxrandom width flakes. Thickness swell was measured on specimens subjected to an OD-VPS test, relative humidity exposure between 30 and 90% and a 24 hour water soak. The order of increasing thickness swell was lathe, disk, ring and drum cut flake panels with values ranging from 12-16% during relative humidity tests. However, flaker species interactions did occur and flaker choice should still be determined by actual flaker tests.

Vital, Wilson and Kanarek (1980) developed equations to predict and optimize conditions for minimizing thickness swell and linear expansion based on experiments with boards made from Douglas-fir. Four flake thicknesses (0.15, 0.41, 0.66 and 0.91 mm) and three flake lengths (13, 25 and 51 mm) were studied. Flake width was held constant at 1 inch. For flakeboard, thickness swelling was among others a function of the geometric terms SAWT - surface area by weight and RTxTKN - (resin type)x(flake thickness). Furnish length was not significant either alone or in product terms. The smallest thickness swell was predicted

for boards made with flakes 0.30 mm thick and of any length.

Price and Hse (1983) investigated structural flakeboards made with hardwoods and utilizing several flake thicknesses and lengths. Once again, thickness swell increased as flake thickness increased. For a given flake thickness, there was no observed effect of flake length. Thickness swell averaged about 14% for 30-90% relative humidity exposure tests.

3.2.2 Linear Expansion

Many of the authors reporting the effect of particle configuration on thickness swell also measured linear expansion data.

As with thickness swelling, thin flakes appear to enhance linear stability. Turner (1954) showed, Figure 10, that boards made with 0.23x70x25 mm flakes had about half the linear expansion experienced by boards made with 0.46 mm thick flakes in relative humidity tests from 30-90% (0.12% versus 0.25%). Boards made from 0.18 mm side length cubes had about 20 times the linear expansion (2.6%) displayed by boards made with sound fibers. Increased flake length also contributed to increased linear stability.

Heebink and Hann (1959) showed linear expansion was lower, over all relative humidity levels, for 25 mm flakes (0.30%) over 0.25" flakes (0.55%) and increased further for planar shavings (0.57%), slivers(0.75%), fines(0.81%) and sawdust(1.41%). (Bracketed values are

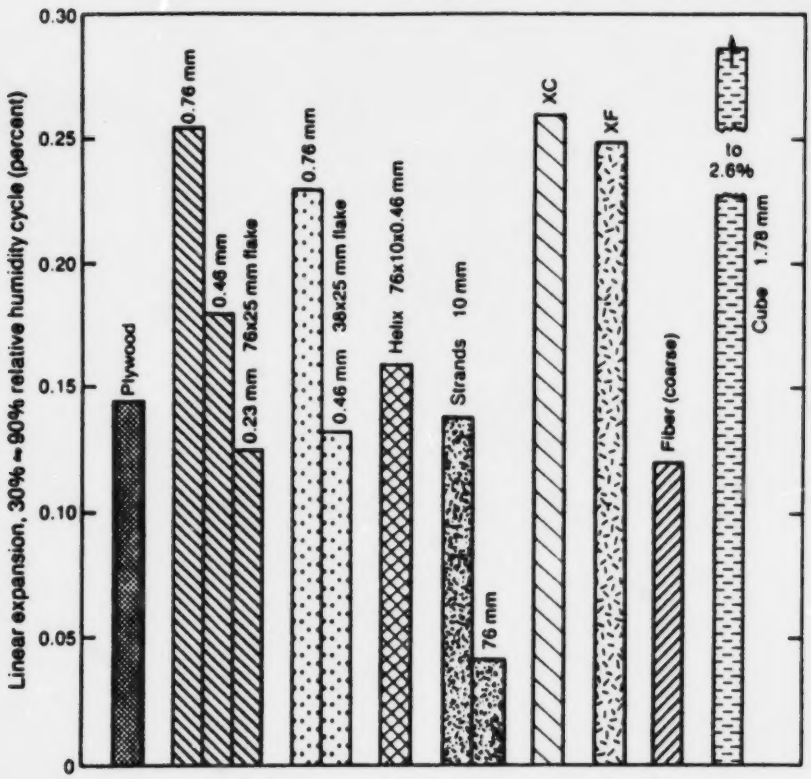

Figure 10: The effect of particle dimension and shape on linear expansion. (Drawing after Turner, 1954)

at 90% relative humidity.) Sawdust, similar to the cubes used by Turner, had 20 times the linear expansion than the 25 mm flakes. Brumbaugh (1960) found that flake thickness had no effect on linear expansion after 2 hours water soak but was significant after 24 hours with boards made from thin flakes expanding less. The unaveraged data, illustrated in Figure 11, shows that the 13 mm long flakes had greater linear expansion than the 102 mm long flakes over all flake thicknesses. The author expressed some concern that equilibrium was not being approached close enough in the 24 hour soak to cause well differentiated effects. Post (1961) found linear stability was not greatly affected by changes in flake length or thickness for flakes less than 0.30 mm thick. However, both total and irreversible linear expansion increased as flake thickness increased above 0.30 mm and flake length decreased. In 50-90% relative humidity tests linear expansion was about 0.24% for boards made with flakes less than 0.30 mm thick and decreased from 0.83-0.63% for 1.27 mm thick flakes as flake length increased from 13 to 102 mm.

Dosondil (1966) felt thicker shorter flakes do not overlap as much with other flakes as longer, thinner flakes and thus are not as restricted in movement within the plane of the board.

Gatchell, Heebink and Hefty (1966) found increased linear expansion at all relative humidity levels for boards made with flakes thicker than 0.38 mm and for flakes shorter than 25 mm. Linear expansion measured from 30-90% relative humidity was 0.27% for 25x0.38 mm flakes, increasing to 0.37% for 25x0.76 mm thick flakes and to 0.35% for 13x0.38 mm flakes. No effect was noticed by decreasing flake thickness

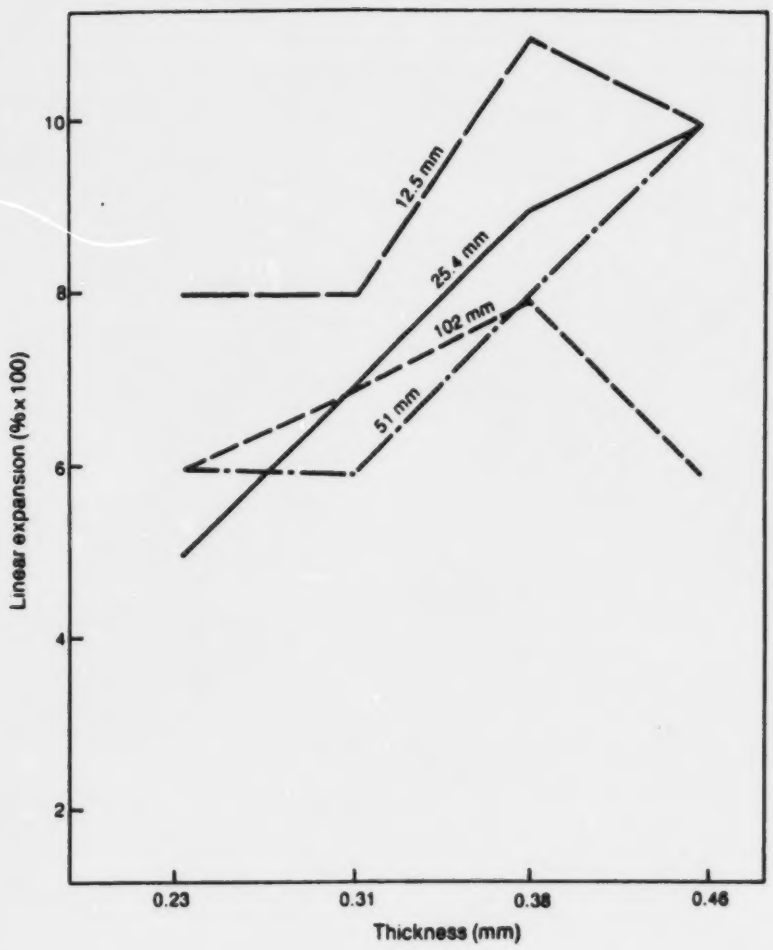

Figure 11: The effect of flake length and thickness on linear expansion after 24 hour water soak. (Drawing after Brumbaugh, 1960)

below or flake length above these levels. Slivers(0.78%) and shavings(0.54%) each showed higher linear expansions than the standard flake shape(0.27%). The authors felt that the flat shape of the standard flakes was better at providing restraint of the longitudinal grain on the transverse grain than the cylidrical shape of the slivers.

Work with cross-grain knife planed hardwood flakes by Stewart and Lehmann (1973) showed panels made with this furnish were more stable than those made with 0.38 mm flakes of equal length prepared on a laboratory disk flaker. In 30-90% relative humidity tests average linear expansion was 0.13% for cross grain flakes versus 0.23% for disk cut flakes. The authors felt that much of the tendancy to swell linearly due to radial or tangential swelling of the flakes could be relieved within the small, interior, partial separation between the fibers in the cross-grain planar flakes. Thus expansion may not have accumulated across the board.

Lehmann (1974) found linear expansion after 5 test exposure conditions (24 hour and 30 day water soak, OD-VPS, 30-90% and 50-90% relative humidity tests) was primarily dependant on increased flake length. Best results were achieved with 51 mm long flakes. Thin flakes gave better results in water soaking tests but had virtually no effect in humidity exposure tests. Results are therefore not independant of the test method used. Overall range of linear expansion in 30-90% relative humidity testing was 0.09-0.20%.

Work by Price and Lehmann (1979) found lathe cut flake panels made from

5 different wood species expanded less under OD-VPS tests than did disk, ring or drum cut flake panels. This was true for all species but one in the 24 hour soak test but not true for the 30-90% relative humidity test, where linear expansion averaged about 0.17%. No reason was given for the apparent superiority of the lathe cut flakes under the more severe test conditions.

Vital, Wilson and Kanarak (1980) found flake thickness was important, alone and in combined terms, in predictive equations for the hygroexpansivity factor - linear expansion/water absorption. Flake thickness (TKN) appears in the terms TKN, TKN^3 and in cross terms RTxTKN, SAWTxTKN and ΔRHxTKN, where RT = resin type, SAWT = surface area by weight, and ΔRH = change in relative humidity. The most important term after ΔRH was the interaction term SAWTxTKN. This term probably related to the ability of each flake to generate and transfer stress as a result of water absorption. The equation predicted lowest linear expansion for thin flakes of any length or flakes longer than 30 mm and of any thickness.

3.3 Resin and Wax

Both resin type and level play key roles in determining the dimensional stability of panel products. Although OSB and waferboard are both made with phenol formaldehyde (PF) resins, literature dealing with urea formaldehyde (UF) resin will also be discussed. Alternate resin systems are discussed under the special treatments section as they are not currently common practice and frequently require special equipment, chemicals and additional process steps.

3.3.1 Thickness Swell

Increased resin levels have been found to be key to increased thickness stability. Phenol formaldehyde resins are more resistant to severe testing conditions and actual outdoor weathering tests than urea formaldehyde resins. Wax appears to only retard water absorption and thickness swelling in the short term, however it can greatly influence the stability of boards exposed to long term weathering by enhancing the board's ability to shed liquid water.

Turner (1954) investigated the effect of 3 levels of phenolic resin (2,4 and 8%) on irreversible thickness swell after 2 water soak-oven dry cycles. Swelling was reduced in all cases by increases in resin content. For flake type particles, increasing the resin content from 2% to 8% reduced irreversible thickness swell from 60% to 40%.

Heebink and Hann (1959) found that the addition of 1% wax to 8% UF

bonded particleboards lowered the rate of water absorption for boards of all particle types and the rate of thickness swell for boards made with fine particles in the 24 hour soak test. Boards made with flake type particles showed no improvement with wax addition and had average thickness swells of 22%. There was no significant difference in thickness swelling due to wax at any level of humidity exposure or water soak after two months of conditioning.

Gatchell Heebink and Hefty (1966) investigated the effect of varying PF resin levels (2, 4, 6, 8 and 10%), wax levels (0, 1, 2 and 4%) and resin type (UF or PF) on 'standard' boards made with 6% PF resin and 1% wax. Stability was measured at different relative humidity exposures and after a 30 day water soak. Above 80% relative humidity, increasing resin levels greatly improved thickness swell behavior whereas wax had no real influence. In the 30 day water soak test, thickness swell decreased from 46% at 2% resin to 17% at 10% resin. Boards made with UF resin had somewhat better thickness stability in relative humidity tests but were poorer in the water soak test. UF resin boards experienced 34% thickness swell after 30 days water soak as compared to 25% for PF resin boards.

After one year of natural exposure tests at different sites, increasing resin content from 2% to 10% decreased thickness swell from 9% to 2%. The addition of 1% wax had a significant effect on reducing thickness swell during outdoor exposure (4% for 1% wax, 12% for no wax) but further addition of wax did not improve results. Neither UF nor PF resin was superior in all cases. Accelerated aging tests showed

improved thickness stability with an increase in resin content and again there was no noticeable effect of wax. There was no way to directly correlate the results of accelerated aging with the one year exposure data.

Three levels of PF resin (3, 6 and 9%) were studied by Lehmann (1974) in Douglas-fir flakeboards made with 1% wax. Thickness swell was measured by 5 methods (24 hour and 30 day water soak, OD/VPS and 50-90%, 30-90% relative humidity tests). Total thickness swell was primarily dependant on resin content for all of the tests and as was irreversible thickness swell after accelerated aging tests. Improvements in thickness stability achieved in increasing resin content from 3 to 6% (27-20%) were greater than increasing resin content from 6 to 9% (20-17%) in 24 hour water soak tests. Irreversible thickness swell after accelerated aging decreased from 44% to 20% as resin level increased from 3% to 9%.

Beech (1975) found a consistent decrease in thickness swelling on increasing the resin content from 9 to 12% in PF bonded Scots pine particleboards. Thickness swell was measured after 1,2 and 24 hour water soak, 2 hour boil and cycling between 1 week at 30% and 1 week at 87% relative humidity. After 24 hour water soak, total thickness swelling decreased from 10% to 7% as the resin level increased. Irreversible thickness swelling was reduced 40-50% (range: 1.6-6.3%) and accounted for most of the decrease in total thickness swelling. The author felt that increasing the resin content reduced irreversible thickness swelling by improving bonding between the wood particles.

Greubel and Paulitsch (1977) investigated PF bonded particleboards and measured thickness changes when boards were exposed to changes in relative humidity from 65% - 30% - 90% all at 20 C. Increases in resin from 7 to 13% decreased the dimensional stability in the change from 65 to 30% relative humidity (range: -2 to -1%) but increased dimensional stability in the change from 30% to 90% (range: 7-12%).

Gertjejansen et al. (1978) found phenolic resins bonded particleboards made from a mixture of Philippine hardwoods had somewhat lower total(14%) and irreversible(9%) thickness swelling after relative humidity exposure from 50-90% than UF bonded boards(15% and 11% respectively). Dimensional stability increased with increasing resin content for both resin types. In 24 hour water soak tests, UF bonded boards had thickness swell decrease from 26% to 15% as resin level increased from 5% to 8%.

Barnes and Lyons (1978) showed phenolic bonded particleboards swelled less after one year of outdoor weathering (8%) than UF bonded boards (13%). Wax appeared only to retard the swelling of UF boards by providing a protective effect in the short term against liquid water. Total and irreversible thickness swelling of weathered PF boards after 24 hour water soak (7% and 0.5%) were also better than weathered UF boards (12% and 4%).

Resin content (3, 5 and 7% PF) and wax content (0, 1, 1,5 and 2%) were varied by Lehmann (1978) in tests on Douglas-fir flakeboards. Boards were soaked in water at four different time and temperature combinations

and exposed to cyclic tests of VPS-OD and WS-OD (water soak-oven dry). Figure 12 shows that in the static water soak tests, resin content had the most obvious effect in reducing thickness swelling and temperature determined the rate at which the limiting thickness swell was reached. Wax only retarded the thickness swell at low temperatures and the addition of more than 1% wax showed only marginal improvement. Similar results, shown in Figure 13, were observed in the cyclic tests.

Price and Lehmann (1979) observed that thickness swelling decreased from 18% to 13.5% as PF resin content increased from 5% to 8% during 24 hour water soak test. Vital, Wilson and Kanarek (1980) found PF bonded boards were more stable at high relative humidity than UF bonded boards.

The effect of varying the resin application rate, application method (air-spray, airless spray or sonic), and temperature (20, 40 and 60 C) was investigated by Lehmann (1965, 1968) using Douglas-fir flakeboards. UF resin was applied at 6% with 0.75% wax and PF resin was applied at 4%, no wax. Thickness swell was measured during water soak and relative humidity exposure tests. In 24 hour water soak tests, lowest thickness swell was observed for the 6% UF boards where fine atomization was achieved (13%) and highest thickness swell was observed with 4% PF boards with coarse atomization (21%).

Further work by Lehmann (1973) looked at three resin levels (2, 4 and 8% UF) and two degrees of resin atomization for boards made with Douglas-fir flake-particle mixtures. Increased resin content improved the total and irreversible thickness swell in relative humidity tests.

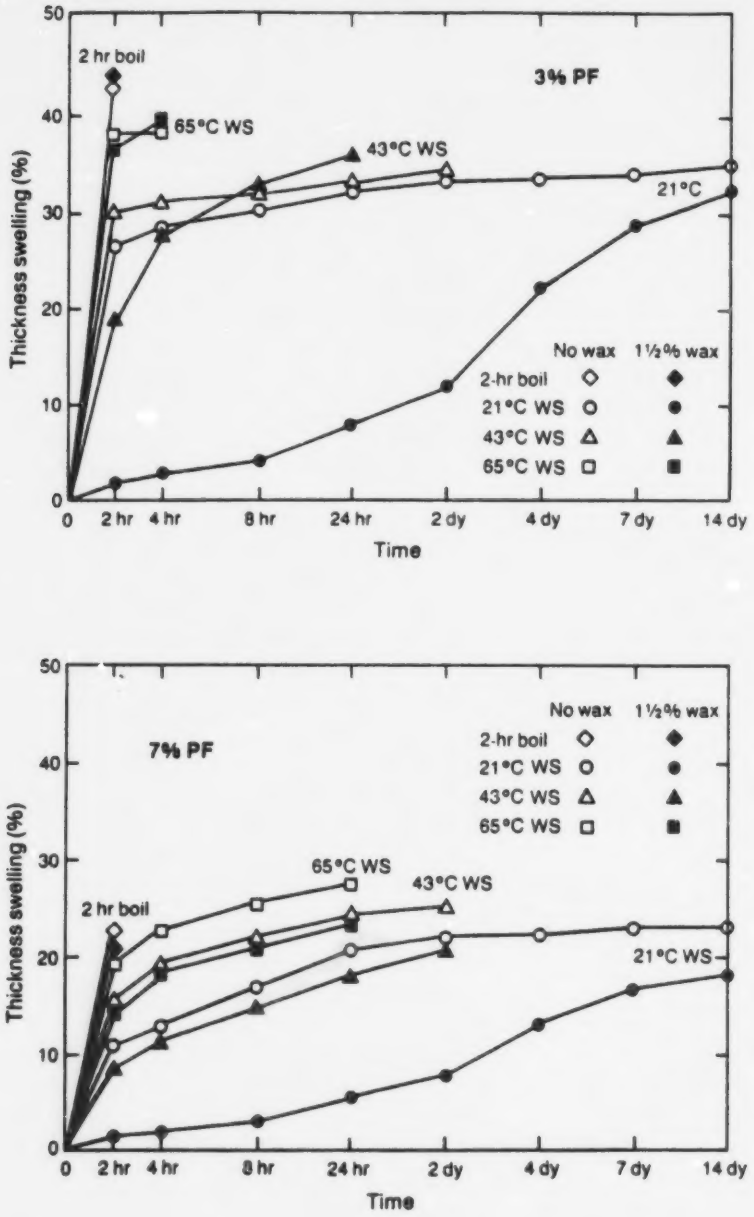

Figure 12: Thickness swelling of flakeboards bonded with 3 or 7% PF resin in various static water soak tests. (Drawing after Lehmann, 1978)

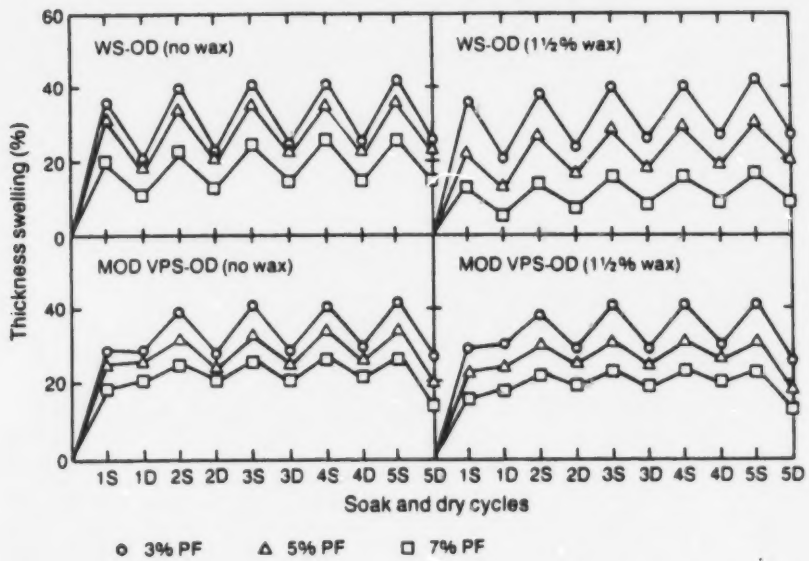

Figure 13: Effect of wax and resin content of thickness swelling of flakeboards during cyclic exposures. (Drawing after Lehmann, 1978)

Fine atomization reduced irreversible thickness swell especially at low resin content. Figure 14 shows the effect of the variables on OD/VPS samples, illustrating the poor dimensional stability at low resin levels and coarse atomization.

Snyder, Rice and Hart (1967) investigated the effects of resin modification (age and viscosity), resin catalysis, spray rate and temperature on yellow poplar flakeboards made with 8% UF resin. Thickness swelling was measured after 24 hour water soak. The most significant factor was found to be resin catalysis which appears to improve the completeness of resin cure. Thickness swell decreased from 40% to 15% when catalyst was used. The other factors did not significantly affect thickness swelling.

3.3.2 Linear Expansion

Turner (1954) measured linear expansion from 30-90% relative humidity at 3 PF resin levels (2,4 and 8%). No clear trends were apparent from the raw data and the author did not comment on the effects of resin levels on the Linear expansion measurements.

Heebink and Hann (1959) found the same results applied to linear expansion as were found for thickness swell. That is, the addition of 1% wax lowers the rate of water absorption and thus linear expansion after 24 hour water soak, but there is no apparent difference between samples that were conditioned for 2 months at any level of exposure. At 0-90% relative humidity exposure, linear expansion varied from 0.28% to

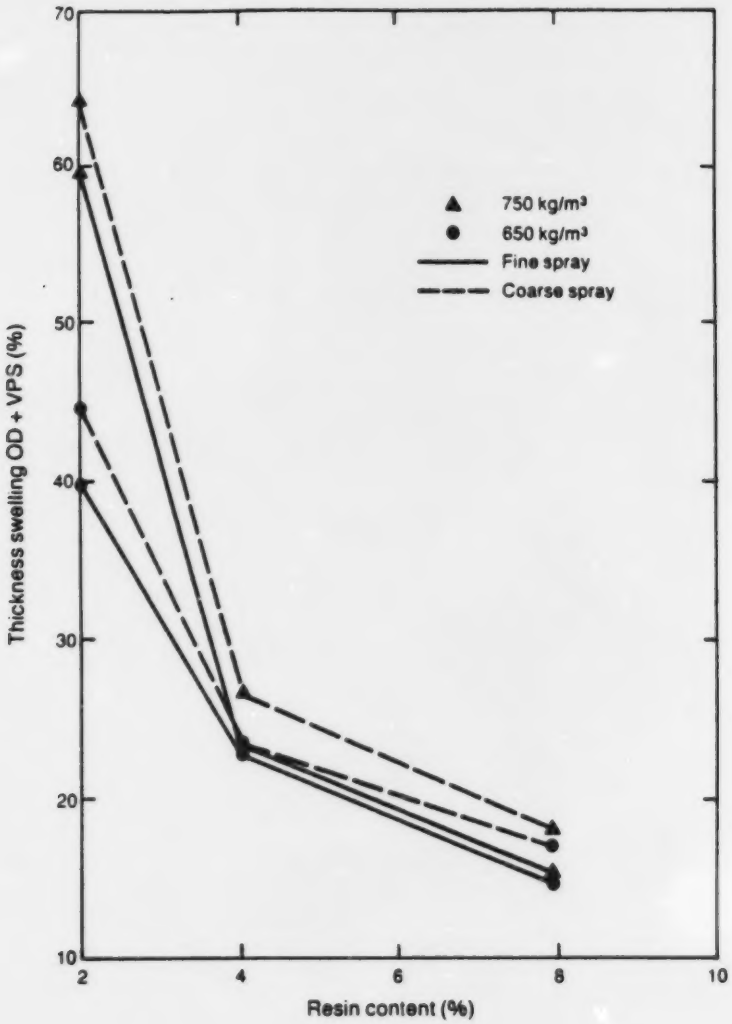

Figure 14: Effect of resin content and application method on thickness swelling. (Drawing after Lehmann, 1973)

0.50% for boards made from flake type particles, with or without wax.

Gatchell, Heebink and Hefty (1966) found very little effect of resin level or wax content on linear expansion over the ranges considered (2 to 10% resin, 0 to 2% wax). At 0-90% relative humidity exposure, linear expansion ranged from 0.27% to 0.30% over the full range of resin and wax. At high humidities and water soak, less linear expansion was observed for the 6% PF bonded boards than for the 6% UF bonded boards, with all values less than 0.35%. Slight improvement in linear expansion for 9% PF resin boards over 3% boards was found by Lehmann (1974) in both 30-90% relative humidity tests (0.13% versus 0.12%) and OD/VPS tests (0.30% versus 0.26%). Gertjejansen (1978) investigated Philippine hardwood mixtures and found lower linear expansion from 30-90% relative humidity as PF or UF resin levels were increased from 5 to 8% (overall range: 0.15-0.38%). Linear expansion for the PF boards was less than for the UF boards for equivalent board types.

Greubel and Paulitsch (1977) investigated changes in linear dimension as PF bonded boards (7, 9, 11 and 13%) were exposed to changes in relative humidity from 65% - 30% - 90% at 20 C. As illustrated in Figure 15, linear expansion was greater during both changes for the higher resin content boards and ranged from -0.08% to -0.13% for the change from 65% - 30% relative humidity, and from 0.18% to 0.27% for the change from 30% - 90% relative humidity.

Natural weathering of UF and PF boards was studied by Barnes and Lyon (1978). UF boards showed lower linear expansion after weathering (0.19%

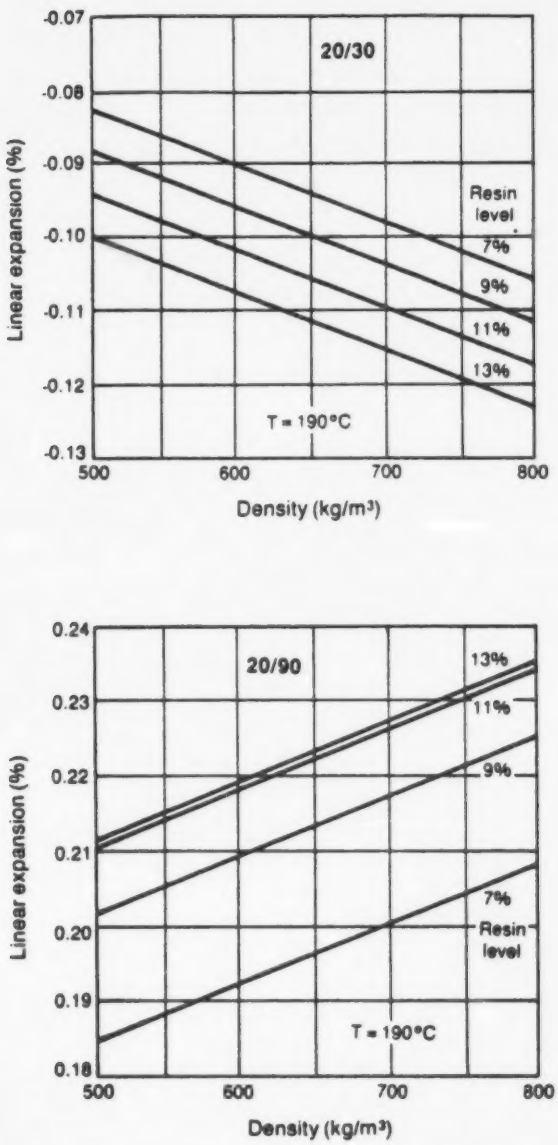

Figure 15: Effect of resin level on linear expansion during relative humidity exposure tests. (Drawing after Greubel and Paulitsch, 1977)

versus 0.28%) on 50-90% relative humidity tests whereas PF boards remained unchanged (0.23%). This was attributed to stress relaxation of the UF boards during the repeated wetting and drying cycles. However both UF and PF boards both displayed higher linear expansion values after weathering as measured by VPS tests (range: 8-10%). This was probably a reflection of the hydrostatic force pushing water into the void spaces and expanding the sample. The correlation between the two test methods was very poor.

Lehmann (1978) found little change in linear expansion due to changes in PF resin level (3 to 7%) and wax content (0 to 2%) during 4 different water soak tests and 2 cyclic tests. The cyclic test results are presented in Figure 16.

Lehmann (1965) found application of resin as a fine spray improved linear expansion as did the use of PF rather than UF resin and lower resin temperature. Lowest linear expansion in the 30-90% relative humidity tests was achieved with 6% UF resin, 1% wax at fine atomization (0.22%) and highest linear expansion occurred for 4% PF resin with coarse atomization. Further work (Lehmann and Hefty, 1973) showed study variables (2,4 and 8% PF resin, coarse or fine atomization) had virtually no effect on linear expansion below 80% relative humidity. Above this humidity level and for VPS tests, Figures 17 and 18 show that 4% and 8% resin gave much better results than 2% resin. The difference in linear expansion between 4% and 8% resin was much less than the difference between 2% and 4%. Degree of atomization was only significant at low resin content and VPS testing.

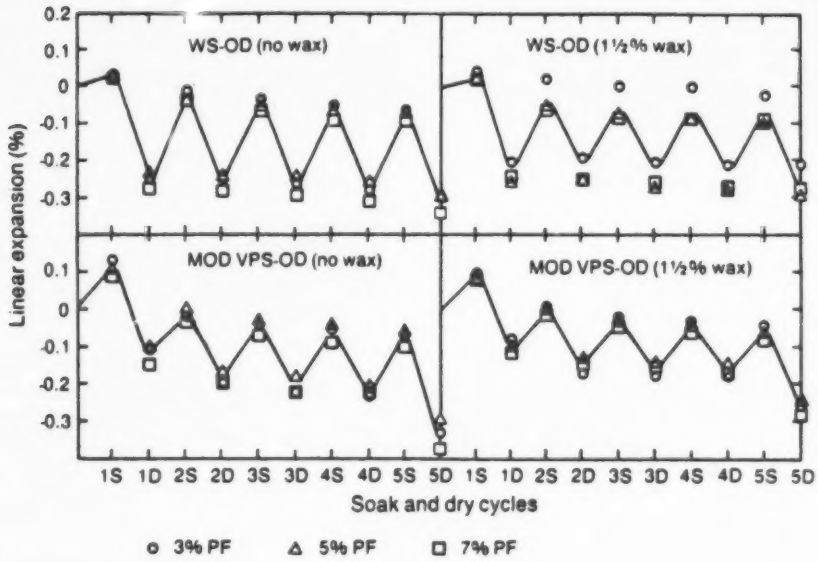

Figure 16: Effect of wax and resin content on linear expansion during cyclic exposure. (Drawing after Lehmann, 1978)

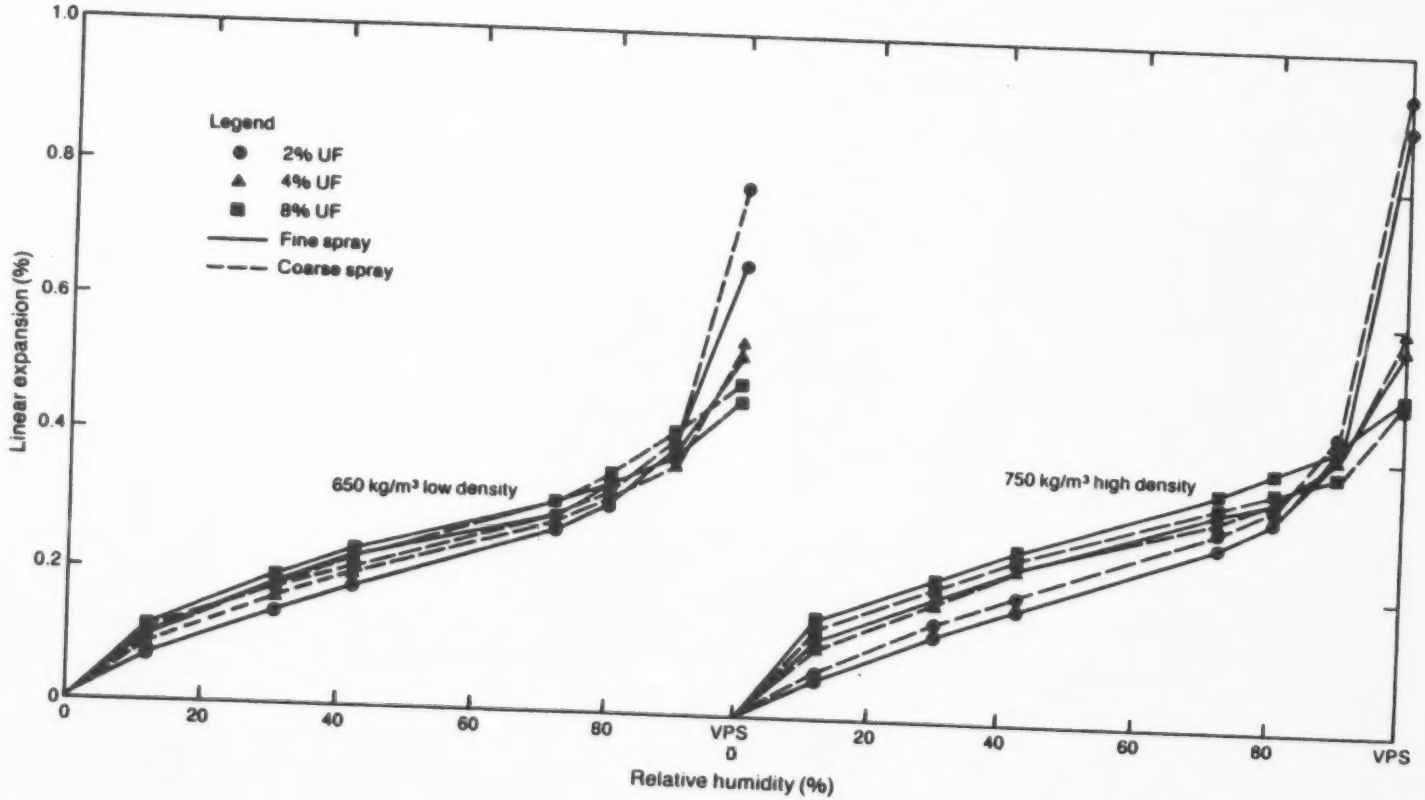

Figure 17: Effect of resin content and application method on linear expansion. (Drawing after Lehmann and Hefty, 1973)

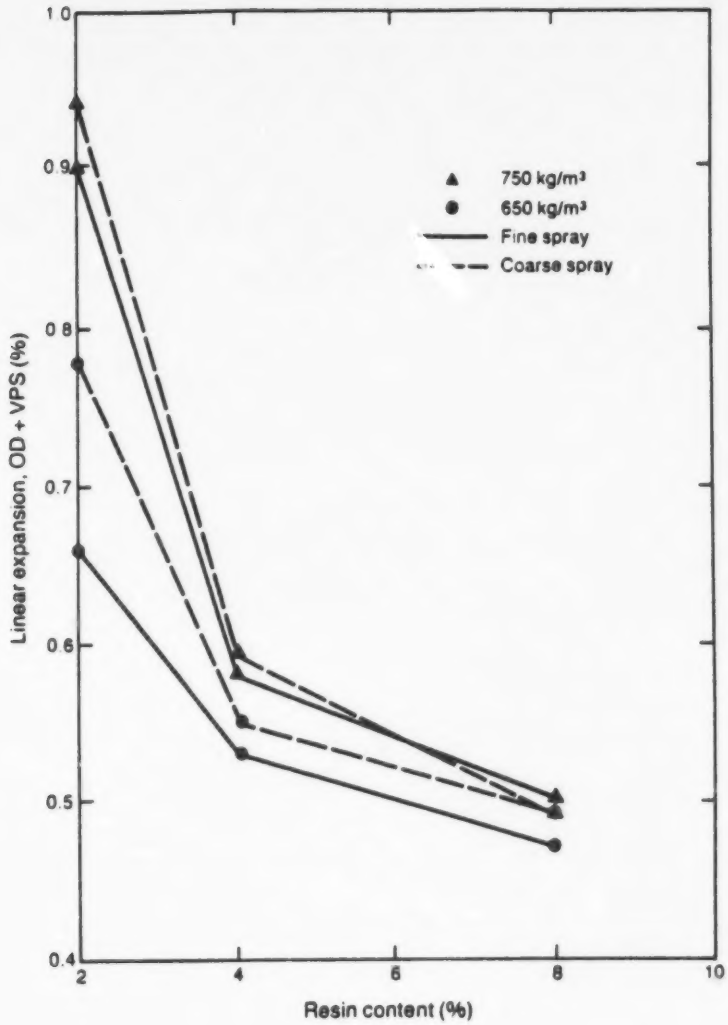

Figure 18: Effect of resin content and application method on linear expansion in OD-VPS exposure. (Drawing after Lehmann and Hefty, 1973)

4.0 Special Treatments

The use of special treatments to improve the dimensional stability of panel products has followed the lead of solid wood research. Thus the basic principles used to stabilize solid wood have been applied to both the wood furnish and the finished panels in an attempt to decrease dimensional movement. Stamm (1964) categorized these treatments as falling into one or more of five types:

1) Lamination
2) Water resistant surface coatings
3) Reduction in hygroscopicity of the cellulose materials
4) Bulking the wood fibers
5) Cross-linking the Cellulose chains.

The special treatments that have been attempted for use with particle board include acetylation, heat and steam treatment, external coating and special bonding systems using cross-linking agents.

4. 1 Acetylation

Wood consists essentially of 70% polysaccharides (cellulose and hemicellulose) and 30% lignins. The water-attracting property of wood is due to a large extent to the hydroxyl groups located in these materials. Selective replacement of those hydroxyl groups which can come into contact with water, by less hygroscopic groups should improve the dimensional stability of wood and wood products. One of the most practical reactions involving hydroxyl groups is esterification with an

acid anhydride. When acetic anhydride is used, the reaction is called acetylation.

Acetylation of solid wood and paper has been found to be an effective method for improving the dimensional stability of these products without a great loss in strength (Stamm, 1964). Acetylation is carried out by exposing the wood to acetic anhydride and a catalyst such as pyridine in either the liquid or vapour phase. In reconstituted wood products, the technique has been applied to both the wood furnish and the finished boards.

Klinga and Tarkow (1966) first investigated the effect of uncatalyzed vapor phase acetylation on the properties of non-heat treated wet processed hardboard (Asplund and Masonite). They found a thickness swell associated with acetylation of the boards that was both appreciable and correlated, Figure 19. This thickness swell was attributed to the bulking of the wood fibers and release of compressive stresses. Figure 19 also shows that both reversible and irreversible thickness swelling in 65-100% relative humidity cycles decreased substantially. Other effects noted were the increase in tensile strength and MOE with the degree of acetylation along with an increase in the surface roughness of the boards.

Aurora, Rajawat and Gupta (1981) compared the properties of boards prepared from acetylated and normal particles of wood. The particles were overdried, soaked in freshly dried pyridine and placed in an acetylation chamber with a mixture of acetic anhydride and pyridine.

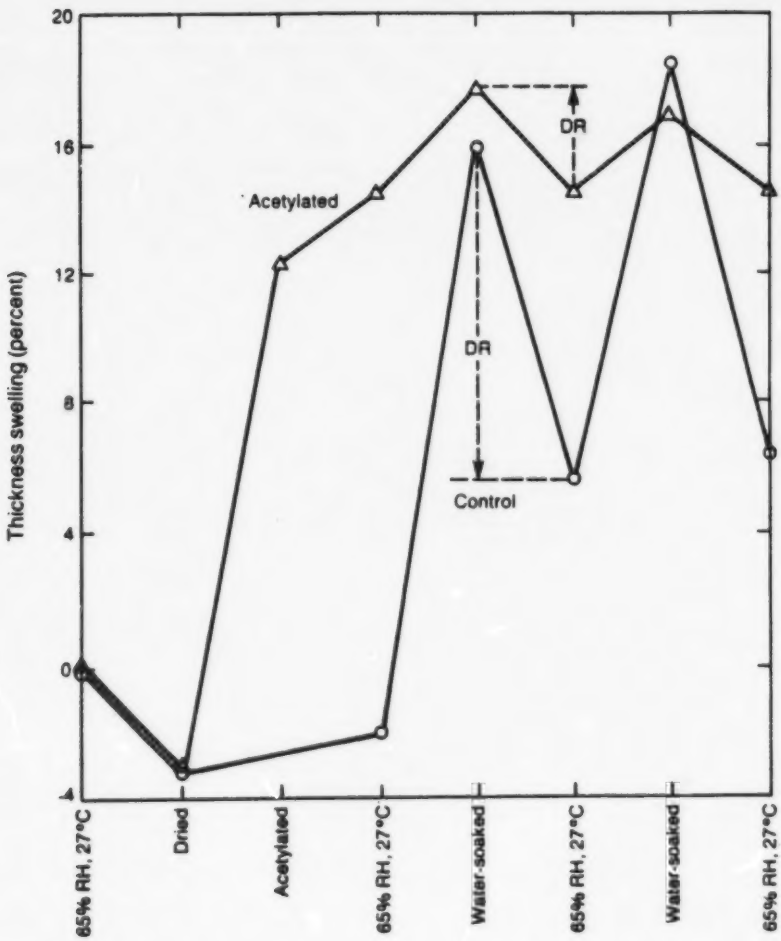

Figure 19: Thickness swelling of a Masonite board on drying, acetylation and relative humidity exposure. (Drawing after Klinga and Tarkow, 1966)

After the desired degree of acetylation had been achieved, the particles were washed in hot distilled water to remove excess chemicals and boards were made with phenol formaldehyde resin. Thickness swell and water absorption were measured at 30, 50, 70 and 100% relative humidity and compared to oven dried boards.

Thickness swell of the treated wood boards was reduced over the untreated boards for the five wood species considered. At 100% humidity, thickness swelling in untreated boards ranged from 20-30% while boards made with treated particles ranged from 10-20%. The increased size or 'bulkiness' of the acetyl group relative to the hydroxyl group is believed to prevent the penetration of the water molecules and hence reduce both water absorption and thickness swell. MOR and MOE increased and the loss of sample by mycological attack was reduced.

Youngquist, Krzysik and Rowell (1986) studied aspen flakeboard made with aspen flakes that had undergone acetylation by 1) complete immersion in a treating solution of acetic anhydride/xylene or 2) exposure to vapors of acetic anhydride/xylene. Boards were made with ring-cut flakes and 6% P.F. resin. These boards correspond quite well to the waferboard concept.

Although not enough boards were made for rigorous statistical analysis the following trends were observed :

1) Ten day water soak test : Untreated boards had thickness swells of 49% (42% after 24 hours) compared with acetylated boards which

had thickness swells of 9% (7% after 24 hours).

2) Twenty day exposure to 90% relative humidity : untreated boards had thickness swelling of 21% and were still increasing after 20 days. Treated boards stabilized after 5 days exposure and had thickness swells of only 5%.

The chemical treatment of the chips did not affect the values of internal bond. Both liquid phase and vapour phase acetylation gave weight gains of about 15%.

Rowell and Ellis (1978) showed that chemically modified wood swells to near its green dimensions so that little additional swelling occurs when it gets wet. Rowell, Tillmann and Zhengtian (1986) reacted aspen, southern pine and douglas fir flakes with either acetic acid/xylene (1/1 V/V) or butylene oxide/triethylamine (95/5 V/V). Flakes were reacted by immersing in either solution at 120 C and 1,050 kPa for times varying from 1 to 24 hours. Excess solution was removed and the flakes were dried. Boards were made with 6% phenol formaldehyde resin with no addition of wax.

The testing program included 1) a 6 hour water swelling rate , 2) water absorption and thickness swelling after 13 day water soak, 3) 5 day water soak - 2 day oven dry cycling 4) oven dry to 20 days at 90% relative humidity.

Levels of bonded chemical up to 25% by weight were achieved. In water soak tests, boards made with butylene oxide treated flakes had up to 50%

less thickness swelling (27.9%) than control boards (59.6%), while acetylation reduced thickness swelling by 85% (9% versus -53%). Figure 20 shows that repeated water soaking and oven drying cycles gave much lower values for reversible and irreversible thickness swell for the boards made with treated flakes. In 90% relative humidity tests, thickness swell was reduced to 12% from 29% and to 2.5% from 11% for the butylene oxide and acetylated boards respectively. Internal bond measurement made on acetylated boards appeared to be on average better than the controls.

The authors are presently examining the economics of both processes.

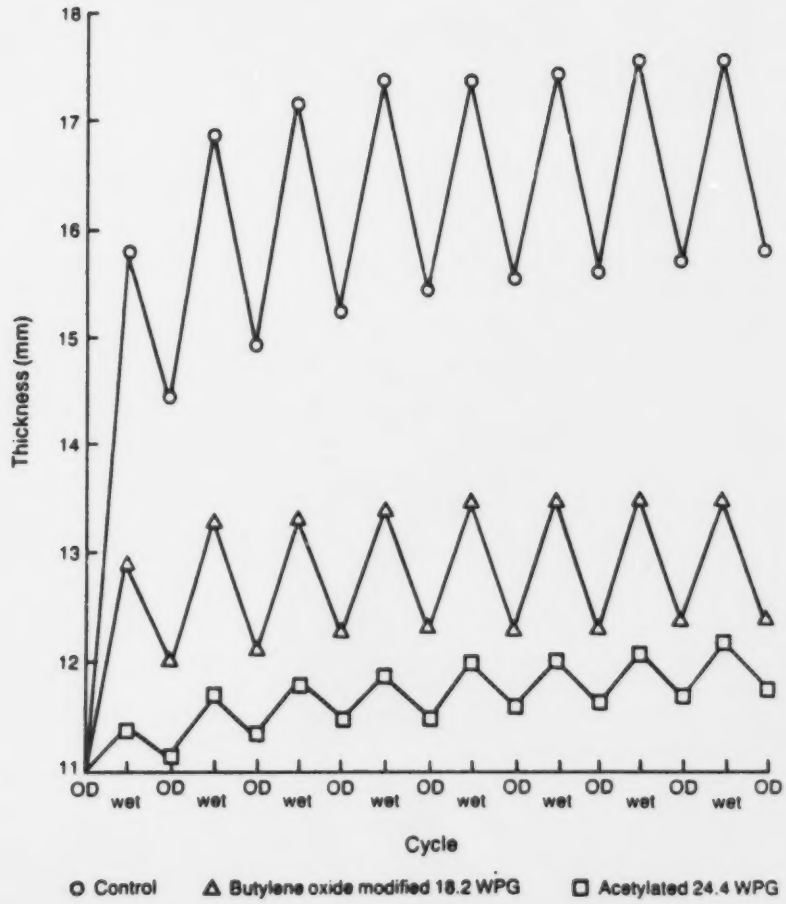

Figure 20: Thickness swelling of chemically modified flakeboard in cyclic testing. (Drawing after Rowell, Tillmann and Zhengtian, 1986)

4.2 Thermal Treatments

When solid wood is heated, preferably in the absence of oxygen, under the correct time-temperature conditions to cause the loss of a small amount of the water of constitution together with other breakdown products, equilibrium shrinking and swelling are substantially reduced. In reconstituted wood products, heat treatment has been applied to both the wood furnish and the finished boards. Steam treatment acts on the same principles as dry heat treatment but at reduced processing times.

4.2.1 Heat Treatment

Heat treatment of oak particles for 1-8 minutes at 230-300 C before board formation was studied by Tomek (1966). Best results were obtained by treating the particles for 4 minutes at 260 C. Water absorption was reduced by 33% and thickness swell was reduced by 45-50% after a 24 hour water immersion test. Modulus of rupture increased by 20%.

Lehmann (1964) however, noticed little improvement in thickness swelling of boards made from planar shavings that had been treated at 205 C for 15, 30 and 45 minutes. In addition, internal bond and modulus of rupture were decreased by 50% and modulus of elasticity decreased by 20%.

Heat treatment of exterior particleboard was studied by Suchland and Enlow (1968). Boards were made with 7% phenol formaldehyde resin, jack pine faces and aspen cores and were post heat treated for .5, 1 and 2

hours at 177 and 218 C. After 2 hours of water immersion there was little difference between the treated boards and the controls but there was and appreciable difference after 24 hours with thickness swelling reduced from 13% to 9%. Most of the improvement in swelling occurred in the first hour of heat treatment and better stability was achieved at the higher temperatures. Both treated and control boards had the same final moisture content after the 24 hour soaking indicating 'stress relaxation' as the probable cause for the increased dimensional stability rather than reduced hygroscopicity. After exposure to 90% relative humidity and subsequent redrying, both reversible and irreversible thickness swelling were reduced in the treated boards. The best dimensional stability results were obtained for 2 hours and 218 C, where reversible thickness swelling was reduced 6% from 10% and irreversible thickness swelling was eliminated.

Modulus of elasticity was reduced at room temperature only for those boards which had been most severely treated indicating some deterioration of the wood itself. There was no observed reduction in strength for treated boards over the controls after both had been exposed to high humidity and redried. Internal bond strength increased at all levels of treatment probably due to additional curing of the resin.

Heebink and Hefty (1969) also heat treated PF bonded particleboards for 2 hours at 218 C and measured thickness swell after the first cycle of a 6 cycle OD-VPS or 6 cycle 2 hour boil/OD test. They observed that thickness swell decreased to 11% from 25% and irreversible thickness

swell decreased to 2% from 11% for treated versus untreated boards. However, boards were very dry after heat treatment rather than at the desired moisture content of 10% for exterior use.

Hujanen (1973) studied the effects of post heat treatment of boards made from 38x0.58mmxrandom width balsam poplar wafer type particles and 3% PF resin. The boards were heat treated for 2 hours at 218 C. Thickness swell was reduced from 13% to 10% during 50-90% relative humidity tests and from 35% to 20% in 50% relative humidity-VPS tests. Linear expansion was not affected and remained at 0.13% after 50-90% relative humidity tests for control and experimental boards. Of the three methods considered in this study, heat treatment appeared to be relatively simple and less expensive than the others. Drawbacks appeared to be the low moisture content of the stabilized boards and the cost of equipment.

4.2.2 Steam Treatments

To reduce the relatively long treatment times required by dry heat treating, Heebink and Hefty (1969) examined treating phenolic bonded boards for 10 minutes with saturated steam at 149-182 C. These were compared to heat treated boards, boards treated with supersaturated steam and boards made with flakes pretreated with steam.

Swelling was measured during a six cycle OD/VPS test or after a 2 hour boil/oven dry test. Saturated steam at 182 C was very effective in reducing reversible and irreversible thickness swell especially at low

resin contents. Thickness swell after the first soak cycle was reduced to about 15% from 20-50% and irreversible thickness swell was reduced to less than 5% from 11-30%. The treatment had very little effect on linear movement and produced only moderate reductions in bending strength and internal bond.

Steam pretreating of the chips was only about half as effective as treating the finished board. Treating the board with superheated steam was not very effective at all, with some increase in both total and irreversible thickness swell. The other variables studied, such as species, density, resin content and particle shape produced only minor changes in the effectiveness of the standard treatment.

Hujagen (1973) also examined post steaming on wafer type boards made from balsam poplar. Boards were steamed at 182 C for 10 minutes then reequilibrated at 50% relative humidity. Post steaming increased board thickness by 16%, reduced density by 11% and MOR by 30%. Post steaming reduced reversible thickness swell from 13% to 5% in the 50-90% relative humidity test and from 35% to 15% VPS test. Irreversible thickness swelling was reduced from 7% to 0.7% and from 23% to 3% in these two tests respectively. Linear swelling was also reduced, although not as significantly with all linear expansion measurements between 0.09% and 0.19%. The drawbacks in post steaming lie in the excessive loss of material due to sanding to uniform thickness and the increased processing and steaming equipment required.

Beech (1975) tested boards that had been treated in an autoclave with

saturated steam at a pressure corresponding to 160 C. After treatment the boards were equilibrated to 65% relative humidity and resanded to 18 mm thickness. Thickness swell was measured after 1,2 and 24 hours water soak, 2 hour boil and after 10 cycles between 30% and 87% relative humidity (one week at each level). The authors found steam treatment reduced thickness swell by reducing hygroscopicity of the wood particles and by relieving compressive stresses in the wood particles.

Thoman and Pearson (1976) examined the effects of injecting saturated steam at 14-18 kPa into the mat for 1-3 minutes during the pressing cycle of southern pine particleboards made with 6% PF resin. After a 24 hour water soak, the reversible thickness swell of the treated boards (11%) was about 50% of that of the controls(20%). Upon redrying irreversible thickness swell of the treated boards(3%) was less than 1/3 of that of the controls(11%). This reduction was due to the relief of internal stresses under the plasticizing action of the steam and the lower hygroscopicity of the boards as demonstrated by the reduced water absorption levels. There was no significant difference in the linear expansion properties due to steam pressing. Control boards had higher strength and internal bond values than treated boards.

Giebler (1983) investigated the stabilization of wood and wood products by heat treatment at 180-200 C, 8-10 bar and a defined moisture content. Particleboard, fiberboard and oriented strand board were tested. Thickness swelling after a 24 hour watersoak was reduced from 19% to 5% for the 6% PF bonded, 3 ply oriented strandboard and linear swelling was reduced from 0.3% to 0.16%. There was some reduction in the strength

properties of the boards but a positive side effect was the reduction in formaldehyde emmissions. The economy of the process is strongly dependant on the size of the production facility.

4.3 Polyethylene Glycol

Polyethylene glycol is an effective and simple method to stabilize wood (Stamm, 1964) which acts as a bulking agent to reduce the amount of water the component fibers can absorb. Lehmann (1964) obtained a 15% reduction in swelling with a 5% retention of PEG after 14 days of water immersion and a 50% reduction with 20% PEG. Swelling of boards in high humidity environments was only slightly less for the treated boards over the controls. Mechanical properties were not seriously affected. The use of PEG treatment appears to be restricted to use with phenolic resins as PEG interferes with the curing of UF resins and thus mechanical and swelling properties deteriorate rapidly with increasing PEG.

4.4 Impregnation

Impregnation of wood chips with phenol formaldehyde resins or low molecular weight thermoplastics can give good reductions in thickness swelling.

Brown, Kanega and Gooch (1966) impregnated scrub pine flakes with 10% phenol formaldehyde impregnating resin or 8.5% of a low molecular weight thermoplastic and made boards with either 7% UF or 5% PF binding resins. Both reversible and irreversible thickness swelling were reduced by about 50% at these levels of impregnation during tests cycling between oven dry and equilibrium moisture at 90% relative humidity. After the first cycle, thickness swells of the controls was 14% against 7% for the impregnated boards. Irreversible thickness swell was 2% for the controls with essentially no irreversible thickness swelling for the impregnated boards. The PF bonded boards were superior to the UF boards and the PF impregnant was slightly better than the thermoplastic impregnant in reversible thickness swell.

Ponderosa pine flakes were also impregnated with 20-25% by weight impregnating PF resin and boards were made with 4% bonding PF resin. Cycling between oven dry/ 4 hour boil/ 16 hour water soak conditions gave extremely good thickness swell data with essentially no irreversible thickness swell observed. Strength retention was also excellent. However the extreme levels of resin used make this method prohibitively expensive.

Later work by Lehmann (1968) showed a 23% reduction in thickness swell between 30-90% relative humidity was possible with 2% impregnating PF resin and 4% PF bonding resin.

Haygreen and Gertjejansen (1972) investigated the effects of using impregnating phenol formaldehyde resin in wafer type boards made with balsam poplar and 3% PF bonding resin. The use of 7% impregnating resin reduced thickness swelling during 50%-90% relative humidity tests from 15% for controls to 10% and from 43% for controls to 21% during OD-VPS. Irreversible thickness swell was also reduced by 50% after each test, with impregnated boards having 4% and 13% irreversible thickness swell after the two tests respectively. Slightly better results were achieved by applying the impregnating resin to the green particles rather than to dry particles. Linear stability was affected very little.

Beall, Young and Witt (1975) investigated commercially produced, UF bonded aspen flakeboards impregnated with methyl methacrylated at 60% by weight and subsequently cured and polymerized with gamma radiation from a Co-60 source. Mechanical properties of the treated boards were greatly improved. Thickness decrease for the treated boards was 0.31% during the final 80-30% relative humidity cycle against 2.4% for the untreated boards. During the 24 hour water soak tests, thickness swelling of the treated boards (7%) was 82% of that for untreated boards (8.6%). Introduction of the polymer delayed the absorption of water but there was apparently enough capillarity within the flakes to overcome the absence of large voids within the boards. The cost of methyl methacrylate monomer at the high loadings investigated and the

specialized equipment both contribute to make this method an unlikely candidate for wide spread use in dimensional stabilization.

Shaudy and Proksch (1976) investigated particleboard and fiberboard that were impregnated with unsaturated polyester resins, various monomers and subsequently cured using gamma radiation from a Co-60 source. Tests for thickness swelling followed DIN 52184 and consisted of drying samples under vacuum at 75 C for 1 week followed by water soak for 1 week with vacuum applied several times. Results showed 'coarse' particleboard abaorbed up to 87% by weight of the polymer solution versus 40% for fiberboard. Volumetric swelling of treated 'coarse' particleboards was lower than the 'fine' particleboards and the fiberboard. All of the treated particleboards had volumetric swelling of about 10% versus 20% for the untreated boards. Several accelerators were tested to reduce the curing times required and the best was found to be a mixture of cobalt naphthenate and benzoin methyl ether.

4.5 Oil Tempering

Studies by Hall and Gertjejansen (1974) were conducted to determine if the properties of phenolic bonded particleboards could be improved by oil tempering in much the same way as hardboard properties are improved. Commercially produced particleboards, one made from large flakes and two from planar shavings, were studied. Boards were immersed in 77 C tempering oil until 5 or 10% retentions were achieved and subsequently dried at 149 C for three hours. Linear expansion and thickness swelling were determined using a VPS test and irreversible thickness swell was determined after an ASTM accelerated aging test.

Oil tempering was effective in reducing irreversible thickness swelling in all of the boards. Irreversible thickness swelling for the large flake board was reduced from 32% to 16% at 10% tempering oil retention. Oil tempering decreased total thickness swelling (from 31% to 27%) and linear swelling (from 0.12% to 0.10%) for the large flake board but not the planar shaving boards. The authors estimated the cost of materials for a 5% treatment of a 720 kg/m^3 board would be about $7.60 per 100 m^2 of 16 mm board.

4.5 Coatings and Surface Treatments

Coatings applied to panel products must protect against water vapour and liquid and be resistant to changes in surrounding atmospheric conditions as well as changes in the dimensions of the board. It is particularly difficult to protect the cut edges of panel boards because changes in dimension greater than 5% are common.

Meierhofer and Sell (1977) treated both UF and PF bonded boards with four different surface treatments and exposed them to 3.5 years of natural weathering. Two alkyd resin paints, a mixture of linseed oil and paraffin and 1 oil modified alkyd resin paint (enamel) were tested. The thickness of the coatings was varied and the coatings exhibited a wide range of water vapour permeability and water repellancy. As may be expected, the PF bonded boards withstood the natural weathering much better than the UF bonded boards. Water repellance was found to be a prerequisite for a good coating material whereas water vapour permeability was less important as long as it was above a minimum value. Two-layer treatments were found to be superior to single layer treatments. Overall, the best results, in terms of appearance and irreversible thickness swell, were achieved by the linseed oil/paraffin mixture. The important factors in a good surface coating seemed to be to prevent the penetration of water vapour into the board by sealing large gaps between surface particles and by preventing the penetration of liquid water especially along the cut edges.

Further work by Sell, Sommerer and Meierhofer (1979) under similar

weathering conditions showed that excellent weather protection was achieved by surface treatments consisting of a water repellant primer containing 1-2% paraffin and a covering coat, preferably >150μm, both using a alkyd resin base. Addition of the wax to the primer was found to be more effective effective than adding it to the covering coat and wax in the primer was not detrimental to adhesion. Panels coated with a 1-1.5 mm layer of unsaturated polyester resin showed no thickness swell or loss in strength. Thickness swell results from short duration laboratory tests (high humidity/drying/high humidity/water immersion) did not correlate with those from natural weathering.

Feist, Little and Wennesheimer (1985) measured the moisture excluding efficiency of a range of commercially available surface treatments on wood including panel products such as plywood and flakeboard. Specimens were exposed to 90% relative humidity until the moisture excluding efficiency was reduced to 50% or less, at which point the samples were returned to 30% relative humidity. Of interest was the effect of variables on the length of time required for the change from the initial to the final equilibrium moisture content. The best finishes were found to be 1) an epoxy sheating compound, 2) dipping in molten paraffin wax, and 3) epoxy-enamel paints, pigmented varnishes, soya-tung enamel and a soya-linseed alkyd enamel.

4.6 Alternate Adhesives

Alternate adhesives are gaining interest because they represent an alternative to synthetic adhesives derived from natural gas and petrochemicals. They also represent a potential use for by-products of other wood processing plants and agricultural products.

Philippou et al. (1982) prepared Douglas fir particleboards using a non-conventional bonding system in which wood flakes were activated with hydrogen peroxide and cross linked with mixtures of ammonium lignosulfate (ALS) and/or furfuryl alcohol (FA) in proportions ranging from 10/0 to 0/10. Ferric chloride and maleic acid were tested as potential catalysts. two boards were made for each experimental condition and two 6% PF bonded boards were made as controls. Thickness swelling was measured after 24 hour water soak and after 2 hour boiling tests. The control board thickness swelling was reported as 28% and 47% respectively for the two test methods. The results for the non-conventional boards are shown in Figure 21 as a function of the ALS/FA ratio. The ALS/FA bonded boards were superior over most of the ratios tested. Thickness swelling was also reduced by increasing the resin content from 3% to 11% with the greatest reductions occurring between 3% and 7%. Catalysts had some effect but their role was not fully understood. The most stable boards were made with an ALS/FA ratio of 6/4 at 11% chemical content.

Similar studies by Brink et al. (1983) compared particleboards made using an oxidative pretreatment and a formulated cross linking agent

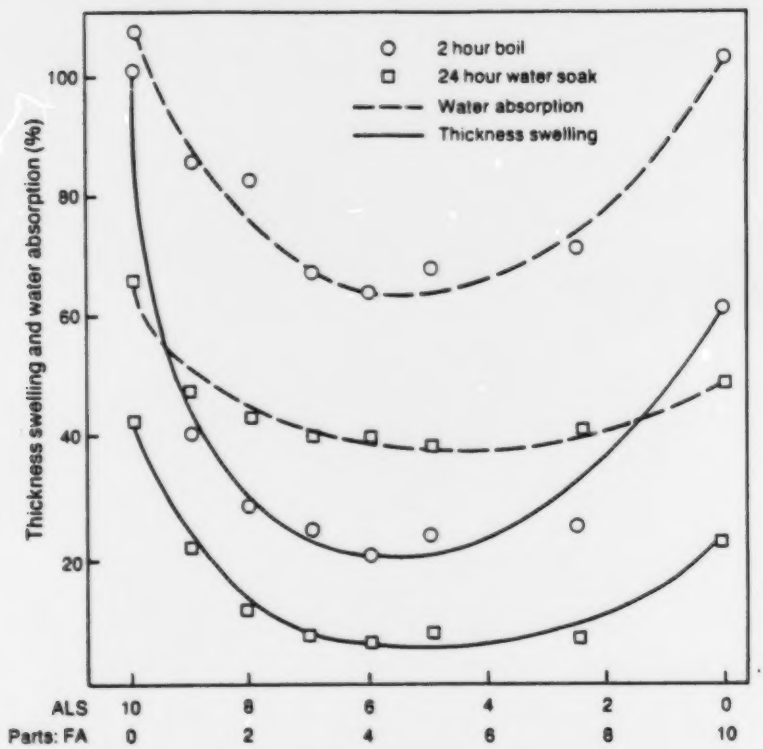

Figure 21: Effect of ALS/FA ratio on water absorption and thickness swelling after 2 hours in boiling water and after 24 hour water soak. (Drawing after Philippou et al., 1982)

(CLA) with conventional 6% PF bonded particleboard. The oxidative pretreatment used either nitric acid or hydrogen peroxide at levels from 0-2%. The CLA was a mixture of lignosulfonates, furfuryl alcohol, maleic acid and water in weight ratios of 4.2:1.8:1.0:5.2 per 100 grams of wood (= 7% by weight bonding chemicals). Thickness swell was determined after 24 hour water soak and after 2 hour boiling tests. Linear expansion was measured after a 2 hour vacuum-pressure soak treatment.

The conventionally bonded 5% PF bonded boards had thickness swellings of ~33% after the 2 hour boil test and ~23% after the 24 hour soak. Boards made with the hydrogen peroxide pretreatment were not acceptable, the low density board failed and the high density board had severe thickness swelling after the 2 hour boil. As illustrated in Figure 22, boards made with nitric acid-CLA were very stable with thickness swells of 14-16% after the two hour boil test and exhibiting almost no variation with board density. The authors felt the high degree of dimensional stability in this test demonstrated that a high level of bonding had taken place, in particular extensive formation of covalent bonds had been achieved. Linear expansions after OD-VPS tests were all less than 0.25%, with most values below 0.20%. Increased flake thickness increased the thickness swell and optimum board making conditions were established at 180 C press temperature, 7 minutes press time, 9.5% mat moisture content and 2 hours of CLA formulation time.

Krzysik and Young (1986) investigated the properties of aspen flakeboards made with base activated flakes and methylolated Kraft

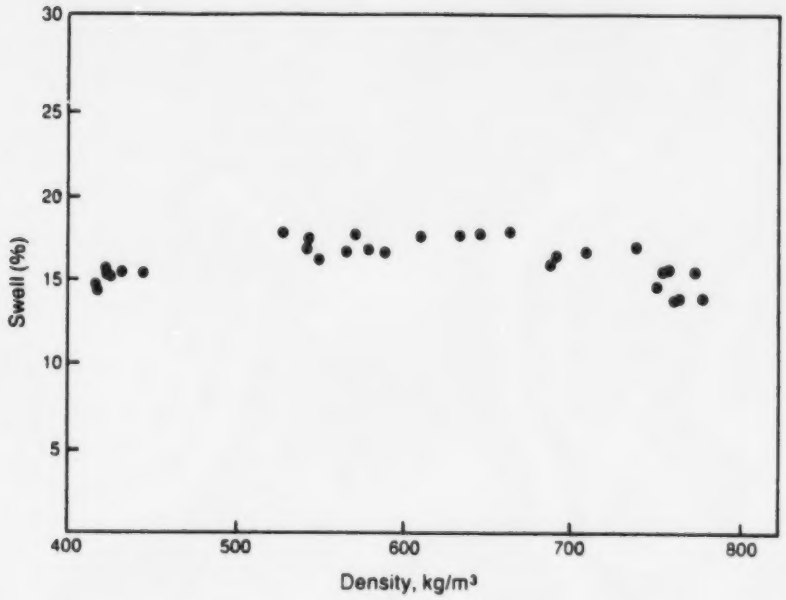

Figure 22: Swelling after 2 hour boil versus density of nitric acid CLA bonded boards. (Drawing after Brink et al., 1983)

lignin with 6% PF bonded flakeboards. Oven dried aspen flakes were activated by 3N sodium hydroxide solution, bonded with Kraft lignin that had been methylolated with formaldehyde and presses for 30 minutes at 176 C. Thickness swell was measured after 24 hour water soak (from oven dry) and after one cycle VPS-OD. Figure 23 show thickness swelling results for three of the lignin resin levels tested and for the standard PF board after 24 hours water immersion. The optimum lignin level appears to be 10% although all lignin levels showed improvement over the conventional board. Total thickness swell and irreversible thickness swell were both lower in the VPS-OD test for all levels of lignin (33%-24% TTS, 13%-3.6% ITS) than for the PF bonded board (38% TTS. 21% ITS). Total and irreversible thickness swell decreased as resin level increased.

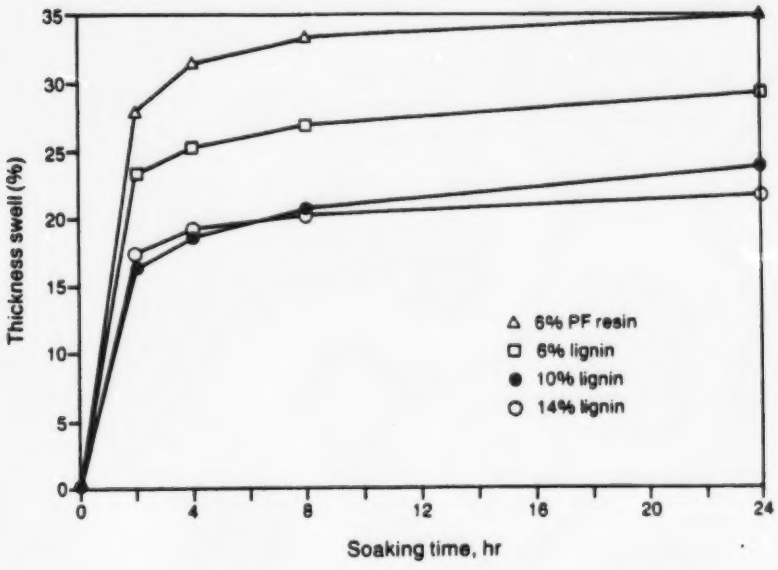

Figure 23: Thickness swell versus soaking time for PF and lignin resin bonded flakeboard. (Drawing after Kryzysik and Young, 1986)

5.0 Conclusions

Waferboard and oriented strandboard have been accepted for use as structural panels in Canada since their introduction in the 1960's. Standards governing acceptable strength and dimensional characteristics have been established in Canadian Standard CAN3-0437.0-M85 'Waferboard and Strandboard'. Although thickness swell requirements are frequently easily met by increasing the amount of resin required to make a panel, this is an expensive alternative to a problem that can potentially be solved by careful control of other process variables such as board density and flake geometry. Some of the process parameters, such as board density, are however not easily modified to maximize dimensional stability without adversely affecting strength and internal bond.

Overall, the following observations have been found to be generally true. Total and irreversible thickness swelling increase with an increase in board density, but the trend is frequently reversed for boards made from low density wood species such as basswood. Board density usually has little effect on linear expansion but slight increases with increasing board density are more common than decreases.

Boards made with thin flakes, less than .030 mm thick, show greater dimensional stability than boards made with thick flakes. The lower wood mass in each particle and the increased number of particle-particle interactions allows better dispersion of particle swelling into interparticle voids. Longer flakes also appear to enhance thickness swelling by dispersing localized swelling stresses over a larger region.

Linear stability is also enhaced by thin flakes and lengths greater than 25 mm.

Increasing resin decreases total and irreversible thickness swelling by improving interparticle bonding. Production conditions which enhance resin cure also decrease thickness swelling. Linear expansion is only affected by resin level at very low resin content. The use of wax seems to retard the rate of thickness swelling and linear expansion but not the final amount after long term or severe exposure conditions. Wax appears to enhance coating systems.

In addition to investigating the effect of process parameters, recent research has also focused on reducing thickness swell by reducing the hygroscopicity of the wood furnish and relieving compressive stresses in panels. The easiest of these methods appears to be thermal treatment of the board, using either steam or dry heat, with steam being less time consuming. Thermal pretreatment of chips was not successful due to severe loss in stregth of the boards. Chemical pretreatment of wood chips by acetylation or impregnation is giving good results but the costs are high. Initial work on alternative adhesive systems also seems to be resulting in strong, stable boards but work is still at a very preliminary stage. Coating systems that are applied by the end user are presently probably the most cost effective way to prolongue the life of boards exposed to natural weathering.

6.0 Recommendations for Further Work

Further work is recommended in the following areas.

1) Basic treatments, as discussed in this review, should be analyzed further for cost effectiveness. In paticular emphasis should be placed on studying cost effectiveness of changing resin/levels, board density and pressing strategy to obtain baseline information. Special treatments would be considered separately.

2) Post heat treatment of finished panels should be persued because of the enhanced dimensional stability that is possible and the availability of energy in Alberta. The trade offs to be made with possible loss of strength properties must be examined.

3) Inexpensive easily applied effective coating systems should be developed with close cooperation between the researchers and the panel board producers to facilitate technological transfer. This represents an easily implemented alternative to major changes in the production plant and would allow the degree of dimensional stabilization required to be tailored to the particular application.

4) Alternative adhesive systems, such as the base-activated/Kraft lignin system, should be investigated because of the potential for boards stable over a wide density range and the potential for better utilization of a wood processing by-product.

5) In the Canadian context, waferboard and oriented strandboard are generally made from aspen. The dimensional stability of boards made from species mixtures, including paper birch, balsam poplar and fast growing poplar clones, should be investigated so that better forest utilization can be achieved.

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